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Utility of the CVLT-II Short Form: Differentiating between subgroups of stroke

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UTILITY OF THE CVLT-II SHORT FORM: DIFFERENTIATING BETWEEN SUBGROUPS OF STROKE

by

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ABSTRACT

Objective: The Short Form of the California Verbal Learning Test - Second Edition (CVLT-II SF) is used to screen ability to learn and recall verbal information. The objective of the current study is to examine psychometric properties of the CVLT-II SF in an inpatient stroke rehabilitation sample, with a focus on this tool's ability to differentiate between performances of three groups of individuals with stroke.

Participants and Methods: Archival data from 75 admissions for inpatient stroke rehabilitation are included in the study. Cronbach's alpha and the Spearman-Brown split-half method are used to examine internal consistency of the learning trials, and a Kuder-Richardson technique is used to analyze the internal consistency of items from the recognition trial. Validity is examined by analyzing correlations between selected CVLT-II SF variables with convergent measures (i.e., tests of attention and memory for verbal information) and discriminant measures (i.e., tests of visuospatial discrimination, verbal abstraction, and cognitive set-shifting). A discriminant function analysis, using seven CVLT-II SF variables, is used to predict membership in three stroke groups: (1) left cortical, (2) right cortical, and (3) subcortical. Predictors include measures of attention span, general verbal learning, delayed recall, recency effect, semantic clustering, recognition discriminability, and recall/recognition contrast.

Results and Conclusions: Internal consistency of the learning trials and items from the recognition trial are judged to be adequate. Validity, based on correlations between the CVLT-II SF and other neuropsychological tests, suggests that the CVLT-II SF assesses attention and memory for verbal information, though may not be a pure measure of these cognitive domains. The discriminant function analysis significantly

differentiates the stroke groups, with a classification procedure correctly classifying over 70% of cases. Individuals with left cortical stroke are well-differentiated from individuals with right cortical stroke and subcortical stroke on the CVLT-II SF, with the left cortical stroke group performing poorer than the other two groups. Measures of attention (Trial 1) and immediate recall (Total of Trials 1 to 4) best differentiate the groups, whereas measures theoretically associated with retrieval of encoded information (i.e., semantic clustering and recall/recognition contrast) do not appear meaningfully related to the discriminant function.

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Background

The ability to learn and remember verbal information is fundamental for successful daily functioning. Impairments in learning and memory commonly follow neurological and psychiatric disorders, although the expression of a person's memory impairment can vary substantially depending on the nature and location of the neuropathology. Due to diverse profiles of memory dysfunction, it is essential to have an assessment tool that is able to examine each individual's learning and memory strengths and weaknesses.

In depth scrutiny of how an individual performs on a particular task, rather than focusing on a single test score, provides useful information about an examinee's cognitive ability. List-learning tasks allow for such an approach, and as a result are useful for describing the memory style of numerous clinical populations. One commonly used measure of verbal learning and memory is the California Verbal Learning Test (CVLT) (Delis, Kramer, Kaplan, & Ober, 1987). The CVLT, developed in 1987, is a brief, individually administered test based on the presentation of lists composed of common English words. There are a number of versions of the CVLT including the Children's Version (Delis, Kramer, Kaplan, & Ober, 1993), the original Adult's Version (Delis et al., 1987) and the revised CVLT-II for Adults (Delis, Kramer, Kaplan, & Ober, 2000). The CVLT and the CVLT-II can efficiently provide information that contributes to a clinician's ability to measure an individual's cognitive strengths and weaknesses, formulate an educated diagnosis, and develop rehabilitation programs specially tailored to meet the needs of each patient's distinct memory deficit. Memory performance appears to be related to functional outcome, and can be influential when suggesting recommendations about level of supervision required, ability to perform activities of daily living (e.g., self-care, cooking, monitoring medications, and driving), and ability to return to the workplace (Kessler, Cohen, Lauer, & Kausch, 1992; Kibby, Schmitter-Edgecombe, & Long, 1998; Taneja, Rourke, & Hanks, 2004). Evaluations using the CVLT have even demonstrated utility in the detection of individuals who may be malingering (Baker, Donders, & Thompson, 2000; Coleman, Rapport, Millis, Ricker, & Farchione, 1998; Millis, Putnam, Adams, & Ricker, 1995; Sweet et al., 2000).

The CVLT-II includes an abbreviated form, known as the CVLT-II Short Form (CVLT-II SF). The CVLT-II SF, which is the focus of this investigation, is designed for use as a screening instrument. According to the developers, the purpose of this brief version of the CVLT-II is twofold (Delis et al., 2000). First, the CVLT-II SF is useful for assessing patients with moderate to severe levels of cognitive dysfunction who may not be able to withstand the cognitive demands of the original version; whereas, the standard version may frustrate subjects with impaired cognition or susceptibility to fatigue, the CVLT-II SF is thought to be less overwhelming. Second, due to the shorter length of the word list and fewer subtests, the CVLT-II SF is quicker to administer than the standard form of the CVLT-II. The short form can be completed in 20 to 30 minutes, whereas the standard form takes approximately 45 to 60 minutes. Considering the extensive time required to complete a comprehensive neuropsychological battery, the brevity of this tool is of unmistakable value.

Despite the extensive literature documenting the clinical utility of the CVLT and the CVLT-II standard forms, research on the utility of the abbreviated CVLT-II SF is scarce. Resembling the original CVLT and CVLT-II, the test developers suggest that the CVLT-II SF is useful for investigating: (1) the quantity of material learned, (2) the rate of learning across several trials, (3) the encoding strategy utilized, (4) serial position effects, (5) the types of errors made, (6) vulnerability of memory to distraction, and short- and long-delays in time, and (7) the degree to which verbal memory improves when recall cues are employed (Delis et al., 2000). Although the CVLT-II SF has the potential to be useful for assessing patterns of memory in various populations, this has not yet been examined.

Stroke is a medical condition that is widely known to have an influence on memory, as well as other cognitive functions (e.g., Tachibana et al., 1999; Tatemichi et al., 1994; Wade, Parker, & Langton Hewer, 1986). The degree of clinical, cognitive, and psychosocial impairment varies depending on the location and severity of stroke. The heterogeneity of the neuropsychological sequelae in stroke includes different patterns of memory impairment. In order to assess memory dysfunction in stroke patients, measures of memory should be able to distinguish patients with varied pathophysiological damage. For example, memory impairment due to cortical strokes should be distinguished from memory impairment resulting from subcortical strokes. Also, patients with left hemisphere damage should be distinguished from those with right hemisphere damage.

The major objectives in the current investigation are to examine aspects of the internal consistency and validity of the CVLT-II SF in a sample of stroke patients admitted for inpatient rehabilitation, and to determine if the CVLT-II SF can be used to distinguish between patients with different types of stroke. This paper also provides a summary of background information on memory functioning after stroke. This review begins with an overview of the epidemiological characteristics of stroke, followed by a description of diagnostic criteria used to describe stroke, the neuroanatomy and pathophysiology of stroke, and the cognitive characteristics of stroke, with an emphasis on the heterogeneity of verbal memory deficits. A description of the CVLT-II SF and its various indices follows. An investigation of how different groups of stroke patients perform on the CVLT-II SF remains the focus of this paper.

Epidemiology of Stroke

Stroke, the most common life-threatening neurological disease, is one of the main causes of death, disability and illness worldwide (American Heart Association, 2002; Health Canada, 2000; Wolf & D'Agostino, 1998). Each year in North America about 650,000 people suffer from stroke, with roughly 500,000 first time attacks. Nearly seven percent of deaths in North America are attributed to stroke; making stroke the third leading cause of death behind only heart disease and cancer. The majority of deaths occur within the first few days after a stroke, although 20 percent of stroke patients are reported to die within the year post-stroke.

Of reported strokes, approximately 83 percent are ischemic, 10 percent are intracerebral hemorrhages and 7 percent are subarachnoid hemorrhages (American Heart Association, 2002; Health Canada, 2000). Most strokes are small (lacunar) subcortical strokes (Longstreth et al., 2002). Of MRI-defined infarcts in elderly individuals, most infarcts are small (< 20 mm) and occur in subcortical regions (79%) (Longstreth et al., 2002). Seventy-two percent of people who suffer from stroke are above the age of 65. In general, the incidence of stroke is similar in men and women; however, at older ages the incidence in women is higher than in men. More than half of stroke deaths occur in women. This is presumably because women have a higher life expectancy, and as the proportion of elderly within the population increases, the prevalence of, and total number of deaths due to stroke increases.

Incidence varies in terms of race; for example, African Americans have a 38 percent greater risk of stroke compared to Caucasians, and African Americans are more likely to die of stroke (American Heart Association, 2002; Rasool, Rahman, Choudhury, & Singh, 2004). Hispanics, American Indians/Alaskan Natives, and Asian/Pacific Islanders have somewhat lower rates of stroke than African Americans but higher rates than Caucasians.

The proportion of deaths from stroke has declined approximately 50 percent over the past 20 years (Health Canada, 2000; Muntner, Garrett, Klag, & Coresh, 2002; Wolf & D'Agostino, 1998). This decline is attributed to both improved survival following stroke and decreased incidence (Malmgren, Warlow, Bamford, & Sandercock, 1987; Thorvaldsen et al., 1997). Incidence rates appear correlated with public awareness efforts directed towards smoking cessation, healthy nutrition and weight, regular physical exercise, and medical management of risk factors such as hypertension and other cardiac diseases, including hyperlipidema, and diabetes (Health Canada, 2000). Understanding of the warning signs may also lead to more immediate treatment and as a result fewer deaths. In addition, improved neuroimaging allows for diagnosis of previously undetected smaller cerebral infarcts and hemorrhages, possibly contributing to the lower proportion of stroke-related deaths. Continued measures to better understand predisposing factors and facilitation of prevention is crucial.

Today, in North America there are nearly 5 million stroke survivors. Increased survival means that more patients are living with disabilities, and potentially require long-term assistance from their families, the community, and the health care system (Muntner et al., 2002). Strokes result in longer average hospital stays than most other causes, and higher total cost based on hospital expenditures, medical care, drugs, and research (Health Canada, 2000). Stroke is the leading cause of serious, long-term disability with greater than a million American adults reporting difficulty with functional limitations and activities of daily living (American Heart Association, 2002). Although the majority of stroke survivors regain functional independence, 20 percent require institutional care at three months post-stroke, and up to 30 percent are permanently disabled (American Heart Association, 2002).

Approximately a third of stroke survivors demonstrate significant cognitive impairment (e.g., Patel, Coshall, Rudd, & Wolfe, 2003; Tachibana et al., 1999; Tatemichi et al., 1994; Wade et al., 1986). In a study of 163 stroke patients assessed at 3 months, 1, 2 and 3 years after stroke, Patel et al. (2003) revealed that prevalence rates of cognitive impairment were 39%, 35%, 30%, and 32% respectively. Over half of stroke survivors complain about impairments in memory (Sorensen, Boysen, Jensen, & Schnohr, 1982). In terms of objective measures of memory, one month post-stroke 9 percent of stroke survivors demonstrate mild memory impairment and 15 percent demonstrate moderate to severe memory impairment when asked to recall past events (Prescott, Garraway, & Akhtar, 1982). Performance on tests of immediate auditory attention appear within normal limits in many stroke patients, whereas measures involving recall of verbal and nonverbal information reveal impairment in about one third of stroke survivors six months post-stroke (Wade et al., 1986).

Nomenclature and Diagnostic Criteria of Stroke

Having discussed the epidemiological magnitude, it is important to understand the definition and etiological classification of stroke. The term "cerebrovascular accident" has generally been abandoned, because strokes may originate from the heart or carotid arteries, rather than always stemming from cerebral vasculature. The World Health Organization has defined stroke as "rapidly developed clinical signs of focal (or global) disturbance of cerebral function lasting more than 24 hours (unless interrupted by surgery or death), with no apparent nonvascular cause" (Thorvaldsen et al., 1997).

This abrupt development of neurological deficits results from a disruption of cerebral hemodynamics, and thus anoxia, hypoglycemia, and decreased energy (adenosine triphosphate) to the brain due to blockage or rupture of an artery to the brain (Pulsinelli, 1992). Adequate cerebral blood flow is crucial for efficient energy metabolism and maintenance of brain pH and metabolic homeostasis; in fact, the brain requires approximately one litre of blood each minute (Toole, 1990, pp. 28-29). As neural tissue has high metabolic demands, including approximately 20-30% of the body's oxygen, it is not surprising that even brief disruptions to regional blood flow can lead to cell death or necrosis.

Cerebral infarction, the death of many neurons within a localized region, may occur by means of several types of vascular pathology (Mohr, Fisher, & Adams, 1980). For treatment purposes, it is crucial to differentiate stroke from other medical conditions, and to separate the major types of stroke. Accurate diagnosis can be obtained by means of medical history and examination, blood tests, and neuroimaging of the brain and its blood vessels. The main categories of cerebral infarction are defined below.

Ischemic Strokes

The majority of strokes are ischemic, resulting when perfusion descends below critical levels, as a result of narrowing or occlusion of arteries (Mohr & Sacco, 1992). Most often ischemic strokes result from atherosclerosis, deposition of plaques on the vessel wall, or an obstructing clot known as a thrombus (Mohr & Sacco, 1992). Risk factors for atherosclerosis or thrombotic strokes include hypertension, heart disease, smoking, diabetes, high-fat diets, and a history of transient ischemic attacks.

Less frequently, an occlusion may result from an embolus, which is a tiny blood clot or other foreign material (e.g., clumps of bacteria, gas bubbles, or fat plug) that breaks loose from an artery outside the brain, most often from within the heart (Mohr & Sacco, 1992). The embolism is carried through larger vessels into smaller ones located in the brain, and at some point jams in an artery too small to allow its passage. Embolic strokes most often involve middle or posterior cerebral artery involvement.

Cerebral vasculitis is an uncommon type of obstructive ischemic stroke that occurs because of inflammation or vasospasm (constriction), which narrows the vessel wall resulting in restricted blood supply. Spasmodic contraction of blood vessels may result from migraine headache, hypertensive encephalopathy, substance use (typically amphetamine use) or vascular anomalies. Various clinical patterns identified include: 1) acute, subacute, or recurrent encephalopathy, 2) rapidly progressing focal, space-occupying lesions, and 3) a syndrome of relapsing and remitting symptoms due to white matter lesions, not unlike multiple sclerosis (Scolding et al., 1997).

Another type of ischemic stroke, usually less severe than the other types, is a lacunar stroke, which produces hollow cavities when small vessels deep within the subcortical regions of the brain are occluded or do not function adequately (Norrving, 2003). Initial symptoms are not always obvious, but frequently include motor hemiparesis, sensorimotor symptoms, dysarthria (difficulty in speech due to impairments in motor control), and ataxia (deficits in motor coordination). The prognosis is relatively more favourable than other types of stroke in the short term; however, new evidence suggests that after the accumulation of many lacunes, impaired quality of life, cognitive decline, and even vascular dementia may follow.

It should be noted that chronic ischemic white matter disease is not equivalent to ischemic strokes, because stroke requires an acute onset rather than progressive wall thickening due to hyaline atherosclerosis.

Hemorrhagic Strokes

A hemorrhagic stroke results from a vessel suddenly leaking or rupturing. Massive bleeding into the brain puts pressure on surrounding brain tissue causing damage, while further damage is caused by a lack of blood to cells beyond the ruptured area. Most frequently hemorrhagic strokes result from a long history of hypertension, as the constant force of the high blood pressure weakens the vessel walls (Rasool et al., 2004). As a result of a hemorrhage, blood may leak into the subarachnoid space (subarachnoid hemorrhage) or into the brain parenchyma (intracerebral hemorrhage).

Abnormalities of the vessel wall may also result in hemorrhagic strokes. For example, in the case of aneurysms, which are weak areas in the artery often located where arteries bifurcate, vessel walls may become thin and stretched out (Mohr, Kistler,

& Fink, 1992). A sudden, unexplained severe headache may indicate the presence of an aneurysm; however, they often rupture before they are detected. Aneurysms may result in bleeding into the brain parenchyma, ventricular system, or subarachnoid space, resulting in a disruption of cerebral functioning secondary to rupturing, shedding emboli, mass effects (herniation and distortion of brain structures), hydrocephalus, or spasm of cerebral vessels. The bleed interrupts the normal supply of oxygen and glucose and the removal of metabolic by-products to and from brain tissues. In addition, the blood itself has toxic effects on the brain tissue (Fein, 1975). Notably, in individuals with aneurysms, neuropsychological effects are often broader than the pattern anticipated from the site or hemisphere of the aneurysm (Richardson, 1991). This may be due to the fact that the aneurismal hemorrhage is generally more extensive than the aneurysm itself, especially because the hemorrhage can change in size over the first couple days post-stroke.

In rare cases, a hemorrhage may result from the rupture of an arteriovenous malformation (AVM), congenitally abnormal conglomerations of thin-walled vessels between arterial and venous circulation (Stein & Wolpert, 1980). These tangled knots of blood vessels tend to bleed, often oozing slowly, as they are not as strong as normal blood vessels. Symptoms tend to be detected after the first decade, possibly because of the gradual development of the abnormality. Survival may be better after an AVM bleed compared to a ruptured aneurysm, because patients usually become symptomatic more gradually due to less catastrophic bleeds. AVMs may result in varied symptoms including neuropsychological impairments such as memory deficits (Buklina, 2001). Compared to ischemic strokes, AVMs localized in the left or right hemisphere less commonly produce lateralized neuropsychological dysfunction (Brown et al., 1989; Waltimo & Putkonen, 1974), thus caution must be taken when grouping patients with hemorrhagic strokes in laterality studies.

Transient Ischemic Attack

A transient ischemic attack (TIA) is a brief disruption of blood flow to part of the brain. TIAs are often linked to atherosclerotic thrombosis. The symptoms of a TIA are similar to a stroke, for example, TIAs result in neuropsychological deficits, including impaired attention, concept formation, perceptual-motor integration, word generation and memory, but comparatively unimpaired motor and sensory functioning (Delaney, Wallace, & Egelko, 1980; Rao, Jackson, & Howard, 1999). Unlike following strokes, symptoms of TIAs generally disappear after a short time period. By definition, TIAs last less than 24 hours, but most commonly, they last less than ten minutes (Pessin, Duncan, Mohr, & Poskanzer, 1977). Although temporary, TIAs should not be ignored as they may indicate a serious underlying risk that a fatal or disabling stroke may follow. Ten percent of patients will experience a stroke within 90 days after a TIA, especially if the TIA is a result of internal carotid artery stenosis (Solenski, 2004). In addition, TIAs are linked with excess global atrophy compared with age-matched healthy controls (Walters et al., 2003). Consequently, extensive laboratory testing is necessary after a TIA to determine if thrombolytic therapy may be of benefit. Of note, TIAs do not fall under the World Health Organization definition of stroke.

Neuroanatomy of Stroke

Unlike many other types of cerebral pathology, stroke typically causes focal neurological damage. Thus, stroke patients have been instrumental in the study of brain-behaviour relationships, and with the advent of neuroimaging techniques it has been possible to make significant gains in classifying anatomical regions associated with symptoms of stroke including aphasia, apraxia, neglect, higher cognitive abilities, and emotion. The following section provides a review of the neuroanatomy of stroke, in combination with major clinical symptoms and signs of various ischemic stroke syndromes.

The brain is supplied by an anterior and posterior circulation system. The anterior circulation, which arises from the internal carotid artery, supplies the anterior and middle cerebral arteries, and the posterior circulation, which stems from the vertebro-basilar system, supplies the posterior cerebral arteries. Details of this system of circulation are provided below.

Internal Carotid Artery System

The basic distribution of blood supply from the heart to the brain comes from two aortic branches: 1) the left aortic arch supplies the left common carotid artery and left vertebral artery, and 2) the brachiocephalic artery supplies the right common carotid artery and the right vertebral artery (e.g., Tegos, Kalodiki, Sabetai, & Nicolaides, 2000). The common carotids branch into the external carotid arteries and the internal carotid arteries. The external branches, which terminate at the temporal and occipital arteries, can provide collateral perfusion if the internal carotid arteries are occluded.

The major branches of the internal carotid arteries, including the anterior cerebral artery (ACA) and the middle cerebral artery (MCA), supply the anterior and middle regions of the cerebral cortex. The minor branches of the internal carotid arteries, which supply the ophthalmic artery, the anterior choroidal artery, the posterior communicating artery, and the anterior communicating artery, irrigate various subcortical areas.

Anterior cerebral artery. The ACA circulation supplies a considerable section of the medial surface of the cerebral hemisphere, including the orbital and medial frontal lobes, the posterior parietal lobes, the cingulate gyrus, the corpus callosum, the head of the caudate nucleus, the anterior globus pallidus, the putamen, and the anterior limb of the internal capsule (Kumral, Bayulkem, Evyapan, & Yunten, 2002). Strokes involving the ACA are uncommon compared to other major cerebral arteries (approximately 1.3% of ischemic strokes), and are generally limited to small portions of its territory because the anterior communicating artery allows for further supply. In most cases, ACA occlusions affect the internal, sagittal plane of the cortex.

Clinical effects of ACA strokes include contralateral hemiplegia (weakness or paralysis of one side of the body) and sensory loss, primarily in the lower extremities. ACA lesions, especially bilateral lesions, may produce akinetic mutism, in which the individual cannot move or speak despite being alert (Kumral et al., 2002). Infarcts in the supplementary motor area of the frontal lobe can result in difficulties initiating and coordinating voluntary movements. ACA infarcts affecting the mesial and orbital frontal lobes result in symptoms such as personality change, apathy, disinhibition, and depression (DeLuca & Diamond, 1995; Kim & Choi-Kwon, 2000), and frequently urinary incontinence (Kumral et al., 2002).

Unilateral ACA lesions in the dominant, usually left, hemisphere may result in language disturbances, limb apraxia, and lower limb hemiparesis. Left-sided lesions to the supplementary motor region can lead to transcortical motor aphasia, characterized by reduced verbal output despite intact repetition and comprehension (Iragui, 1990; Kumral et al., 2002), bilateral ideomotor apraxia, and right alien-hand sign, which involves complex motor activities performed outside of volitional control (McNabb, Carroll, & Mastaglia, 1988).

ACA infarcts localized to the right side, especially to the anterior cingulate and parietal lobe (near the right temporal-parietal-occipital junction), may result in failure to orient to contralesional stimuli, or in other words, unilateral neglect (Leibovitch et al., 1999). Right-sided ACA infarcts have also been associated with acute confusional state (Kumral et al., 2002).

Infarction to branches of the ACA supplying the corpus callosum results in disconnection of the hemispheres, including left-sided ideomotor apraxia, alien-hand sign, agraphia, and tactile anomia (Kumral et al., 2002). Stroke affecting the caudate nucleus and internal capsule may result in aphasia and unilateral neglect (Kumral et al., 2002).

In addition, ACA and anterior cerebral communicating artery infarcts may result in neurobehavioural impairments, especially memory problems (Damasio, Graff-Radford, Eslinger, Damasio, & Kassell, 1985; Deluca & Diamond, 1995; Diamond, Deluca, & Kelley, 1997; Irle et al., 1992; Volpe & Hirst, 1983). Dense amnesia, described as "Korsakoff-like" has also been documented, even in cases with intact diencephalic and mesial temporal structures (Damasio et al., 1985; Deluca & Diamond, 1995). Furthermore, confabulations are also common in ACA stroke patients (Fischer, Alexander, D'Esposito, & Otto, 1995). In cases where confabulations are manifested without concurrent amnesia, both frontal lobe and basal forebrain involvement are usually present (Deluca & Diamond, 1995).

Middle cerebral artery. The MCA is a major supplier for the lateral perfusion of the cerebral cortex, with branches supplying the frontal, temporal and parietal lobes (Damasio, 1991; D'Esposito, 1997). MCA strokes resulting from blockage to the superior branches have an effect on the frontal lobe and anterior regions of the parietal lobe, those blocking the inferior stem result in temporal and inferior parietal lobe deficits, and infarcts to the lenticulostriate branch affect subcortical regions such as the basal ganglia, corona radiata, and posterior limb of the internal capsule. As the MCA is major supplier, it is not surprising that many strokes result from MCA occlusions.

MCA occlusions can cause severe damage affecting almost an entire hemisphere. Dominant, usually left, hemisphere MCA infarcts may result in profound cognitive disorders with disturbance of language abilities (Alexander & Benson, 1991; Damasio, 1991; D'Esposito, 1997). Infarcts from the superior MCA stem often result in aphasia with impaired ability to produce fluent output but relatively intact auditory comprehension (Broca's type) and also ideomotor apraxia, hemiparesis and hemisensory neglect. In contrast, damage to the inferior division, especially the superior temporal gyrus, may result in language difficulties with deficits in comprehension but intact fluency of output (Wernike's aphasia). Wernicke's aphasia syndrome may also be accompanied by anosognosia (unawareness or denial of a deficit), perseveration, and agitation. Strokes with widespread effects extending anteriorly and posteriorly may result in global aphasia, characterized by nonfluent output and comprehension deficits. Dominant hemisphere lesions may result in symptoms of Gerstmann's syndrome (i.e., agraphia, left-right disorientation, acalculia, and finger agnosia).

MCA infarcts in the nondominant hemisphere, typically the right hemisphere, commonly result in dense contralateral hemiparesis, hemianesthesia of the face, arm, and leg, hemineglect (e.g., D'Esposito, 1997). Just as the left hemisphere is fundamental for language, the right hemisphere is most important for directing attention to the environment. Neglect may be expressed in at least three forms: attentional, representational, and intentional (Daffner, Ahern, Weintraub, & Mesulam, 1990). "Attentional neglect" is the failure to attend to stimuli in the environment that are located in the hemisphere contralateral to the lesion site. "Representational neglect" is a deficit in the ability to imagine objects on the contralesional side of an image (e.g., a stroke survivor may not be able to picture the left side of a building when they are trying to view the whole building in their mind). "Intentional neglect" is the unilateral deficit of exploratory-motor activation on the contralesional side (e.g., when blindfolded a patient is unable to use their right hand to reach over and pick up objects on the left side of a table). The type of neglect corresponds to lesion site, with attentional-representational neglect resulting from posterior right-hemisphere strokes (e.g., posterior parietal lobe and occasionally posterior thalamus), and exploratory-motor neglect resulting from anterior right-hemisphere strokes primarily affecting the frontal lobe.

Other symptoms following nondominant hemisphere strokes may include difficulties with visuospatial ability (e.g., visuospatial construction and perception of line orientation), aprosody (inability to produce and often times understand appropriate intonation), anosognosia, constructional and dressing apraxia, hemiparesis, sensory loss, hemianopia (inability to see in the contralesional visual field), confusion, and agitated delirium (D'Esposito, 1997).

Infarction from the lenticulostriate branches, resulting in subcortical dysfunction, may also result in similar symptoms including motor hemiparesis, aphasia, neglect, and dysarthria.

Vertebro-basilar Occlusive Disease

The vertebral arteries enter at the base of the brain and supply the spinal cord, brainstem, cerebellum, and posterior diencephalons. The vertebral arteries unite to form the basilar artery, which subsequently divides into the posterior cerebral arteries (PCA).

Posterior cerebral artery. The PCA, which branches off the vertebro-basilar system, supplies the upper brainstem, lower portions of the temporal lobe, the hippocampus, the thalamus, and significant portions of the occipital lobe. Infarcts to the PCA often result in visual deficits such as homonymous hemianopia, distortion of visual images, abnormal colour perception, and cortical blindness accompanied by visual hallucinations (with bilateral cortical lesions). Hemiparesis is also common, especially if lesion extends to the thalamus or brainstem (Von Cramon, Hebel, & Schuri, 1988).

Dominant hemisphere PCA strokes affecting the corpus callosum can result in alexia without agraphia (impaired reading despite intact writing and expressive language), which may be accompanied by anomia and visual agnosia (difficulty naming objects despite ability to describe them). Lesions to the dominant occipital-temporal region are often associated with transcortical sensory aphasia, which is characterized by fluent but paraphasic speech and normal repetition, but impaired comprehension and naming. Nondominant PCA strokes may result in unilateral neglect, construction apraxia, and delirium (Caplan, 1988).

Intelligence and insight into deficits are relatively preserved after a PCA stroke (Von Cramon et al., 1988); however, research suggests that they have significant effects on memory. The literature suggests that bilateral posterior cerebral infarctions cause persistent amnesia (e.g., Woods et al., 1982), whereas, left-sided posterior cerebral infarctions appear sufficient to cause verbal learning deficits (e.g., Benson, Marsden, & Meadows, 1974; Von Cramon et al., 1988). Von Cramon speculates that lasting verbal memory deficits post-PCA infarction may result from lesions interrupting the Papez circuit (Papez, 1937), by means of damage to the hippocampus, fornix, posterior parahippocampal gyrus or collateral isthmus, as well as projections to the amygdala. Memory for verbal information is impaired on short- and long-delay recall of words lists in the majority of individuals with left PCA infarcts, whereas immediate auditory attention and knowledge of remote information (e.g., famous people or places) is relatively intact. In contrast, memory for verbal information in individuals with right PCA strokes does not differ significantly from healthy controls.

Subcortical, including thalamic strokes, often result in sensory changes such as sensory loss, pain, distorted taste, as well as depressed mood and an amnestic syndrome. Midbrain strokes, due to occlusions in the labyrinthine artery, can result in a lack of blood to the inner ear, and therefore symptoms of dizziness and nausea. Cerebellar strokes occur when there is an occlusion of the PICA, ICA, and or superior cerebellar artery, and can result in impairments such as ataxia, dysmetria, and decreased motor coordination. Occlusions to the brainstem result in problems with respiration, arousal, and motor abilities. As cognitive abilities are generally intact, strokes to this region can sometimes result in locked-in syndrome.

Collateral Circulation

The clinical consequences of stroke are not only dependent on the location of the stroke, but also on the interconnections between supply systems. Mild cerebral infarctions are unlikely to completely abolish oxygen and glucose to affected areas due to compensatory flow from parallel circuitory pathways known as collaterals, and reticular intercommunications between supply systems, known as anastomoses (e.g., meningeal and capillary anastomoses) (Pulsinelli, 1992; Zülch & Hossmann, 1988). As an example of important connections, the posterior communicating arteries connect the internal carotid system and the vertebro-basilar systems, and the anterior communicating arteries connect the ACAs. Collectively, the two pairs of ACAs and PCAs, the anterior and posterior communicating arteries, and the carotid arteries form a joint network referred to as the circle of Willis. Collateral circulation can maintain homeostasis by controlling pressure and perfusion, and consequently can prevent strokes. For example, individuals with occlusion of an internal carotid artery, but normal collateral blood flow through the circle of Willis, should have normal regional blood flow throughout the hemisphere of the occlusion (Nilsson et al., 1979).

Border Zone ("Watershed") Syndrome

In some instances, an infarct may result from two or more of the arterial systems, and in such cases may lead to watershed or border zone infarcts, as they occur at the junctions of the arterial territories (Zülch & Hossmann, 1988). Watershed infarcts may present as ischemic or hemorrhagic infarctions, and most commonly occur between the MCA and either both or one of the ACA and PCA territories.

Summary of the Neuroanatomy of Stroke

The study of the neuroanatomy of stroke has a valuable role in understanding normal and disordered brain functions. As mentioned, an infarct from localized ischemia may result from stenosis or occlusion to a specified arterial territory, most commonly from the anterior, middle, or posterior cerebral arteries. The clinical presentation of the stroke depends on the location (specific vascular territory), size, and adequacy of collateral circulation and anastomoses around the affected area. Individuals post-stroke may experience the full syndrome of symptoms associated with a vascular territory or they may display specific deficits in isolation. It is important to mention that hemorrhagic strokes may not occur in the traditional vascular territories described (i.e., ACA, MCA, and PCA), but rather have a tendency to occur in the subcortical and cerebellar regions. Hemorrhagic strokes that arise in the traditional territories may extend beyond the reported boundaries of these arteries, and thus signs and symptoms may be more diverse.

Neuropsychology of Stroke

The clinical sequelae following stroke can vary immensely. Symptoms may include long lasting coma, or on the other extreme, symptoms may be transitory and at times may be missed altogether (Dunne, Leedman, & Edis, 1986). Initial symptoms may result from edema, raised intercranial pressure and mass effects (e.g., decreased arousal, poor respiration, enlargement of the pupil ipsilateral to the lesion, upper motor signs including increased tone, reflexes and a Babinski's sign). As neuronal death is relatively slow, often taking several hours to days, the initial symptoms may increase in severity and new symptoms may develop. After the acute effects resolve, later symptoms may be more highly associated with the actual lesion. Classic symptoms include hemiplegia and sensorimotor deficits (Hom & Reitan, 1982; Reitan & Fitzhugh, 1971). As each carotid artery supplies blood to one hemisphere, clinical symptoms are especially notable on the side contralateral to the cerebral damage. Other symptoms may include severe headache at onset, disorientation, speech and language problems, difficulties swallowing, apraxia, blurred or decreased vision, ataxia and dizziness, seizures and changes in cognition.

Limitations of Neuropsychological Studies of Stroke

Extensive cognitive decline is common after stroke; however, investigations reviewing the cognitive consequences post-stroke are surprisingly limited. Unfortunately, many studies focus on specific impairments (e.g., neglect, aphasia or apraxia) rather than general cognitive impairment, whereas other studies are limited to analysis of brief screeners (e.g., Mini Mental Status Exam). Studies are also difficult to compare because they analyze neuropsychological performance at varied times post-stroke. In addition, the neuropsychological effects of stroke are complicated due to varied severity, type and location of stroke.

Furthermore, caution must be taken when assessing cognition in patients who have had a stroke because additional stroke-induced problems such as aphasia or severe confusion may contribute to apparent deficits. Similarly, examiners must be aware of any premorbid problems such as deafness or blindness, and even pre-existing dementia that may never have been previously diagnosed. In addition, understanding of the neuropsychological sequelae of stroke is made more complex because risk factors for stroke (e.g., hypertension, diabetes mellitus, hyperlipidemia, cardiac disease, and age) are also associated with changes in cognitive functioning. For example, hypertension has been demonstrated to have an impact on frontal and temporal lobe functions, and specifically affects attention, memory and concept formation (Waldstein, Ryan, & Manuck, 1991) and adult-onset diabetes has been shown to lead to deficits in reaction time, concentration, verbal memory, and mental flexibility (Asimakopoulou, Hampson, & Morrish, 2002; Meuter et al., 1980).

Taking into account the numerous challenges of assessing cognition in stroke patients, a brief review of various domains of neuropsychological functioning is presented. This section focuses on identifying neuropsychological impairments most commonly reported after stroke.

Overall Cognitive Impairment

Tatemichi et al. (1994) examined cognitive impairment, as a general indicator of intellectual decline, in 227 patients three months after ischemic stroke and 249 healthy control subjects without a stroke history. Cognitive domains included orientation, attention, memory, language, visuospatial skills, and abstract reasoning. Tatemichi et al. found that cognitive impairment, defined by "four or more failed tests," occurred in 35.2% of patients with stroke compared to 3.8% of healthy controls. A corrected frequency, calculated by subtracting the false-positive rate of the controls, produced a proportion of 30.2% of stroke patients with cognitive impairment. Areas of cognitive functioning most often affected included orientation, attention, memory, and language. Greater cognitive impairment was associated with functional impairment, and increased dependent living post-discharge. Others have attempted to replicate Tatemichi et al.'s findings, and even when more rigorous cut-offs are used to define impairment, similar results have been demonstrated (e.g., Hochstenbach et al., 1998).

Hom and Reitan (1990) compared the performance of 60 stroke patients with 20 healthy control subjects on various cognitive and intellectual measures. Their results indicated that overall brain impairment based on the Halstead Impairment Index is significantly worse for stroke survivors than controls; however, little difference was noted when comparing stroke groups based on lesion side (i.e., left, right, or diffuse). Hom and Reitan also compared psychometric intelligence in stroke patients with left, right, or diffuse lesions. Performance on the Wechsler Adult Intelligence Scale (WAIS) indicated that in general, stroke survivors performed worse than controls. In particular, the group with left hemisphere strokes performed significantly poorer than the other groups on Verbal IQ, and the right hemisphere stroke group performed poorer than the other groups on Performance IQ. The right hemisphere stroke group did not perform significantly different from controls on the Verbal IQ. Overall, results are consistent with previous findings of intellectual impairment using the Wechsler-Bellevue I scores with patients with left and right hemisphere strokes (e.g., Reitan & Fitzhugh, 1971). In addition, Reitan (1970) reported that left hemisphere stroke impairs both verbal and nonverbal ability (with Verbal IQ more severely impaired than Performance IQ) to a greater extent than right hemisphere strokes.

Attention and Concentration

In comparison to other domains of cognitive functioning, simple attention may be a relative strength in stroke survivors. Wade et al. (1986) reported that immediate auditory attention was generally not impaired in a group of individuals tested on measures of memory at 3 and 6 months post-stroke. Similarly, Hochstenbach et al., (1998) noted that 14% of stroke patients were impaired on tests of simple attention (e.g., WAIS Digit Span forward and Immediate recall on the first learning trial of a word-list), whereas over 40% were impaired on most other domains of cognitive functioning.

Although basic attention may be relatively intact, significant impairments are common on tests of more complex attention (e.g., working memory). For example, Hom and Reitan (1990) found that patients with either left or right hemisphere strokes perform worse than controls on tests including WAIS Arithmetic, WAIS Digit Symbol, and Seashore Rhythm.

Language

Compared to healthy control subjects, approximately a third of stroke patients display impairment on formal tests of language (e.g., sentence comprehension, verbal concept formation), whereas general fund of information (e.g., WAIS Information) is relative intact after stroke (Hochstenbach et al., 1998). One particular area of difficulty with language is noted on word generation tasks. Hochstenbach et al., (1998) reported that nearly 50% are impaired on word generation tests. Similarly, Rao et al., (1999) found that even when compared to subjects with other types of vascular disease (i.e., TIAs and/or carotid stenosis, peripheral vascular disease), stroke patients perform significantly poorer on tests of word generation.

As expected, stroke patients with left side lesions perform poorer than patients with right side lesions or control subjects on many tests of language. The size of the lesion plays an important role in the severity of language deficits, although, localization in areas such as Broca's and Wernike's areas have shown inconsistent effects on language, especially on recent neuroimaging studies (e.g., Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004).

In one study, approximately 38% of individuals met criteria for aphasia immediately after a stroke, and about half of these individuals still had signs of aphasia when they were discharged from the hospital (Pedersen, Jorgensen, Nakayama, Raaschou, & Olsen, 1995). Generally, grossly intact language ability is reached within a matter of weeks, although the exact time to recover basic language skills is highly dependent on the initial severity of the aphasia. Unfortunately, those with global aphasia often do not recover communication skills to a level considered within normal limits.

Aphasia has a disruptive effect on other areas of neuropsychological functioning, even when tests do not appear to have a verbal component (Hochstenbach et al., 1998). Although a causal relationship should not be assumed as it is possible that basic attention and working memory deficits may have an impact on language processes. Interestingly, in a study of individuals with stroke-induced aphasia, language ability did not significantly predict ability to recall verbal information (Beeson, Bayles, Rubens, & Kaszniak, 1993). Rather, it was indicated that lesion location was a better predictor of performance on a nine-word selective reminding verbal learning task than the scores obtained on an aphasia battery.

In particular, frontal lobe lesions were associated with retrieval deficits, and temporoparietal lesions were associated with immediate recall deficits. Of note, patients with severe aphasia were not included in this study considering that all patients exhibited comprehension and verbal expression ability sufficient to complete the verbal memory task.

Learning and Memory

At two to three months post-stroke, approximately 30% of stroke survivors are impaired on tests involving memory of visual and verbal information compared to control subjects (Hochstenbach et al., 1998), and recently, rates of up to 75% have been reported during the acute states post-stroke (Riepe, Riss, Bittner, & Huber, 2004). Long-term free recall is relatively more impaired than short-term recall or recognition ability, and recall of word lists is relatively poorer than recall for narrative information (Hochstenbach et al., 1998).

Patterns of learning and memory ability also vary depending on severity and location of the stroke (e.g., Burgess, Jeffrey, & O'Keefe, 1999; Kessels, de Haan, Kappelle, & Postma, 2002; Hildebrandt et al., 1998). Strokes affecting the medial temporal lobe and hippocampus are especially detrimental to learning and memory (e.g., Jokinen etl al., 2004). The medial temporal lobe and hippocampus are generally associated with difficulties in encoding information, although can also be indicated in cases of retrieval deficits. In addition, memory impairments, especially for visual information, may result from difficulties with organizational strategy rather than an actual deficit in encoding, storage, or retrieval (Lange et al., 2000).

Overall, greater deficits in memory for verbal material is noted in patients with left hemisphere stroke and greater deficits in memory for visual material is found in right hemisphere stroke survivors (e.g., Riege, Metter, & Hanson, 1980). A detailed review of verbal memory literature with respect to infarct location is provided in the subsequent section.

Sensory and Motor Functioning

Reitan and Fitzhugh (1971) studied lateralization of visual, auditory, and tactile sensation after stroke. They found greater contralateral loss in visual functioning after right hemisphere lesions than left hemisphere lesions, minimal lateralization of simple auditory perception, and significantly more bilateral control of tactile processing by the right hemisphere. Among somatosensory functions, impairments were most prominent in tactile perception. In addition to contralesional sensory deficits, Hom and Reitan (1982) reported poorer ipsilateral performance on sensory-motor tasks following right hemisphere lesions compared with left hemisphere lesions.

More pronounced than somatosensory deficits are impairments in motor functioning following stroke. Reitan and Fitzhugh (1971) examined motor performance in stroke patients and noted significant lateralization of functioning when comparing left and right hemisphere stroke patients. Patients were assessed with the Halstead's Finger Tapping Test, the Smedley Hand Dynamometer, and the Halstead's Tactual Performance Test. Haaland and Delaney (1981) also examined laterality of motor performance in patients with left and right hemisphere strokes, and included control subjects in their study. Haaland and Delaney noticed that motor tasks were disparate in their sensitivity to ipsilateral effects of stroke. In particular, compared to control subjects, when stroke patients used their hand contralateral to the stroke they were impaired on fine and gross motor tasks (i.e., grip strength, finger tapping, grooved pegboard, and maze coordination); whereas, compared to controls, stroke patients using their hand ipsilateral to the stroke were only impaired on fine motor tasks (e.g., grooved pegboard, maze coordination, and steadiness tasks).

Furthermore, the left hemisphere appears to have greater bilateral control than the right hemisphere on motor tasks requiring a series of learning movements, especially when commands are given verbally (Kimura, 1977). The right hemisphere shows more bilateral control than the left hemisphere when movements have a spatial component, for example on measures such as the tactual performance test (Hom & Reitan, 1982).

Finger tapping performance, which is significantly impaired using the hand contralateral to the stroke focus, has been reliably documented in stroke patients. In fact, finger tapping performance has been employed as a means of distinguishing individuals with stroke from individuals with other lateralized brain dysfunction such as tumours (Reitan & Wolfson, 1994).

In addition to impairments in fine and gross motor tasks, approximately 70% of stroke survivors perform worse than neurologically intact control subjects on tests of processing speed such as the Trail Making Test Part A, the WAIS Digit Symbol subtest, and the number of seconds to complete a letter cancellation test (Hochstenbach et al., 1998). Slowed processing speed may have a detrimental effect on other neuropsychological test scores, although is not sufficient to explain the breadth and severity of impairments observed.

Visuospatial Functioning

At least 40% of stroke survivors obtain lower scores on tests of visuospatial functioning compared to control subjects. For example, Hochstenbach et al. (1998) reported that compared to healthy control subjects, 47% of stroke patients were impaired on tests of nonverbal problem-solving and visuospatial construction ability (WAIS Block Design). Ability to draw pictures was impaired in 49% of stroke patients when provided with an exemplar to copy from, and in 59% without an exemplar. In addition, patients with right hemisphere stroke perform significantly worse than patients with left or diffuse stroke on measures of visuospatial construction ability (Binder, 1982; Hom & Reitan, 1990). Of particular interest, Hochstenbach et al. (1998) reported that left-hemisphere stroke patients performed significantly poorer than right-hemisphere stroke patients on all domains except for visuospatial functioning. Additionally, visuospatial neglect is prominent is prominent after stroke. During formal neuropsychological assessment Hochstenbach et al., (1998) reported that 35% of stroke patients display left-sided neglect and 26% display right-sided neglect based on scores that were two standard deviation below controls on a letter cancellation task.

Abstraction and Executive Functioning

Performance on measures of abstraction, working memory, organization and cognitive flexibility, is statistically worse among stroke survivors than normal controls subjects (Hochstenbach et al.1998; Hom & Reitan, 1990). Approximately 40% of stroke survivors perform in the impaired range on tests of working memory (e.g., WAIS Digit Span – total number of words recalled in the backward direction), and 56% are impaired on a tests of cognitive set-shifting ability (Trail Making Test Part B). Not only are stroke patients impaired on “executive functioning” tests compared to healthy control subjects, but also compared to individuals with various other types of vascular disease (Rao et al., 1999) and other types of neurological dysfunction including Alzheimer’s disease (e.g., Kertesz & Clydesdale, 1994).

Socio-emotional Functioning

In addition to the assessment and treatment of cognitive functioning after stroke, psychologists evaluate mood and personality disorders. Pohjasvaara, Vataja, Leppavuori, Kaste, & Erkinjuntti (2001) evaluated depression in 390 ischemic stroke patients using Beck's Depression Inventory at 3 months post-stroke and found that 43.9% met BDI criteria for depression (scoring greater than 10). A psychiatric examination, using DSM-III-R criteria revealed that 25.8% of the patients were diagnosed with major depression and 12.5% with minor depression. At 15-months follow-up 256 of the 390 patients were retested, and 44.6% met the BDI criteria for depression.

Kauhanen et al. (1999) similarly reported that depression was diagnosed in 53% of stroke patients at three months and 42% of patients at 15 months post-stroke. When examining the relationship between a diagnosis of depression and cognitive impairment, results suggested that depression was highly correlated with attention, processing speed, dysphasia, nonverbal problem-solving and memory.

Depressive symptoms are not only apparent soon after stroke onset, but may persist for many years. Dam (2001) examined mood and cognitive status seven years after stroke and noted that stroke survivors continued to have higher rates of depression than healthy control subjects. Twenty percent of individuals who had experienced a stroke met criteria for either major or minor depression, whereas only 11 percent of controls were noted to have depression. Subjects did not differ significantly in terms of cognitive functioning, although stroke patients who were positive for depression experienced more difficulties with concentration and memory than did control subjects.

In addition to clinical diagnosis of depression, emotional liability, indifference, euphoria, and denial of illness are also common post-stroke (Dam, 2001; Kotila et al., 1984). Furthermore, compared to healthy controls, many stroke patients report feelings of decreased life satisfaction and a lower sense of well-being after stroke (Clarke, Marshall, Black, & Colantonio, 2001). This is found to be related to disabilities in activities of daily living, cognitive limitations, worse mental health, and comorbid health problems. Social supports and educational resources are found to moderate the impact of functional status on well-being.

Overall, depression and reports of decreased well-being are common post-stroke and have a negative effect on recovery in functional status and cognitive performance, especially attention and memory, in stroke survivors. This suggests the importance of early recognition and treatment of depressive symptoms, as well as maximizing social support for patients soon after they have suffered a stroke to promote better adjustment and enhance stroke rehabilitation.

Summary of Neuropsychological Findings

Neuropsychological evaluations are important for understanding the relationship between the neuroanatomy of stroke and behavioural outcome, including the capacity for independence when carrying out activities of daily living. The effect of stroke on cognitive impairment is dramatic, with approximately a third of stroke patients experiencing significant global cognitive impairment. Most stroke survivors display marked slowness in processing speed, and nearly half will also show deficits in memory, language, and visuospatial ability.

Stroke patients demonstrate specific lateralized impairments depending on the site and severity of their lesion. Those with left hemisphere strokes more consistently produce general impairment of intellectual functioning and show greater deficits in nearly all domains except for visuospatial functioning when compared to right hemisphere stroke patients.

Fortunately, significant recovery of neuropsychological functioning after ischemic and hemorrhagic strokes generally occurs within the first six months (Richardson, 1991). However, if a progressive decline in intellect is noted, often times with a somewhat fluctuating course, vascular dementia may be diagnosed. The prevalence of dementia after stroke varies with rates from 6% (Madureira, Guerreiro, & Ferro, 2001) to 32% (Pohjasvaara et al., 1998) reported in the literature. Vascular dementia may be caused by an accumulation of multiple strokes (multi-infarct dementia) or a single stroke to a critical region (e.g., upper mesencephalon and/ or thalamus) (Katz, Alexander, & Mandell, 1987).

Memory for Verbal Information Based on Location of Infarct

There is no single structure with sole responsibility for memory functioning, but rather a number of possible interconnections between subcortical and cortical regions. This has lead to the speculation that the various components of memory are mediated by circuits interconnecting various regions. For example, the Papez circuit (Papez, 1937) has been reported to be of importance in memory. This circuit appears to connect the cingulum, the hippocampus, septal nuclei (mammillo-thalamic tract), thalamus, and cortex (Irle & Markowitsch, 1982). In addition, various other circuits are reported to play a role in memory, including the basolateral limbic circuit, which connects the orbitofrontal cortex, the amygdala, and mediodorsal nucleus of the thalamus (e.g., Sarter & Markowitsch, 1985).

Historically there has been a focus on the role of the medial temporal lobe in the attempt to localize anatomical substrates for memory (e.g., Squire et al., 1992). After reviewing investigations of severe amnesia, including the famous case of H.M. who underwent bilateral resection of the medial temporal lobe, the importance of this region is undisputable (Corkin, 1984). Bitemporal lesions, including lesions to the hippocampus, are related to intact attention and working memory, normal initial acquisition, but a rapid rate of forgetting, and thus poor ability to form lasting new memories (e.g., Hermann, Seidenberg, Schoenfeld, & Davies, 1997). This impairment in encoding is illustrated by difficulty with recall as well as recognition tasks, a rapid forgetting of stored information, a tendency to make a high number of intrusion errors, and increased sensitivity to proactive interference (e.g., Delis et al., 1991; Kramer et al., 1988; Massman et al., 1992). A similar pattern of encoding and consolidation deficits is noted in patients with other disorders affecting the medial temporal lobe, as can be observed in the "cortical" dementia literature (e.g., Alzheimer's disease and Korsakoff's disorder), in which the main areas of damage are in the hippocampal-thalamic regions. In addition, recent neuroimaging studies have shown that memory deficits are correlated with white matter intensities resulting from stroke to the medial temporal lobes (Burton et al., 2004).

Left Hemisphere Stroke

The hemisphere of the stroke has an important influence on the aspects of memory functioning that are impaired. Left-sided strokes are predictably correlated with more severe verbal deficits than right-sided strokes (Hildebrandt et al., 1998; Tatemichi et al., 1994; Wagner & Cushman, 1994; Wang, Kaplan, & Rogers, 1975). This is true for both recall for narrative information and word lists. However, within the left hemisphere, there is actually no single location responsible for memory storage. This becomes obvious when we consider the phenomenon of intact remote memory, despite impaired memory for new events. Implying that permanent memory storage occurs in brain regions outside of those affected in amnesia (e.g., Squire, 1982).

Although the medial temporal lobe (i.e., hippocampus, parahippocampal gyrus, entorhinal cortex, and in some instances the amygdala) has been a focus in many studies of memory, the literature on the effects of temporal lobe stroke is limited. Generally, infarcts to the temporal lobe are believed to result in encoding deficits. In one study, individuals with left medial temporal lobe infarcts performed worse than individuals with other types of infarcts on most variables on a German version of the CVLT. In particular, compared to the other stroke groups, the left medial temporal group displayed a flat learning curve, an increased rate of recall from the end of the word list, a high reliance on serial clustering, and poor recognition (Hildebrandt et al., 1998).

The left prefrontal cortex is also of significant importance in memory for verbal information. Traditionally impairments in this region have been reported to be associated with retrieval deficits (e.g., Jetter, Poser, Freeman, & Markovitsch, 1996); however, not all studies have verified this pattern of intact recognition following impaired free recall (e.g., Baldo, Delis, Kramer, & Shimamura, 2002; Hildebrandt et al., 1998). It is conceivable that the left prefrontal cortex plays a role in both encoding and retrieval of verbal information (Fletcher, Shallice, & Dolan, 1998; Lee, Robbins, & Owen, 2000; McDermott et al., 1999). Bilateral and right frontal regions may actually have a more substantial role in the retrieval of verbal information than the left hemisphere in isolation

(McDermott et al., 1999). In general, when compared to control subjects on list-learning tasks, patients with damage to the frontal lobes appear to exhibit impaired recall on immediate and delayed trials, a high number of intrusion errors, reduced semantic clustering, and more errors on recognition tasks (Baldo et al., 2002).

The left insular cortex, which relays information to and from the temporal cortex and limbic system, also mediates memory (Manes, Springer, Jorge, & Robinson, 1999). Manes et al. (1999) compared stroke survivors with left and right insular infarction on various measures of memory and found that individuals with left insular infarctions performed significantly worse on list-learning and story recall tasks than individuals with right insular infarctions. Individuals with left insular infarctions were impaired compared to the normative sample, whereas those with right insular infarctions were within the normal range. No lateralization of memory for visual information was noted.

Right Hemisphere Stroke

The consequences of left hemisphere stroke on memory for verbal information are relatively well documented. In contrast, there has been little attention dedicated to the outcome of right hemisphere stroke on memory for verbal content. This may be a result of the traditional idea that left hemisphere lesions result in verbal impairments, whereas right hemisphere lesions result in visuospatial deficits. Sure enough, studies frequently demonstrate that right hemisphere stroke patients perform within normal limits on tests of verbal ability (e.g., Kertesz & Dobrowski, 1981). Nevertheless, there are exceptions to this pattern.

In terms of learning verbal material, right hemisphere stroke patients perform better than left hemisphere stroke patients, but worse than controls. For example, Moya, Benowitz, Levine and Finklestein (1986) compared individuals with right hemisphere strokes with age-matched controls, and found that the right hemisphere stroke group was impaired on all measures of verbal recall, including list-learning and paragraph recall. In a subsequent study, these authors reported that patients with right hemisphere damage were impaired at abstracting information from narrative passages (Benowitz, Moya, & Levine, 1990). The extent of verbal deficits was highly correlated with the extent of visuospatial deficits.

In an Italian study, Villardita (1987) examined verbal list-learning performance using the Rey Auditory Verbal Learning Test in patients with right hemisphere brain damage and control subjects. On this task, which consists of learning a list of 15 unrelated words, the two groups performed similarly. In contrast, on a list that contained words belonging to three semantic categories, not unlike the CVLT, the group with right hemisphere damage displayed impaired semantic clustering. Furthermore, Villardita, Grioli, and Quattropani (1988) found that in comparison to normal control subjects, patients right hemisphere damage had more difficulty learning and semantically clustering concrete, highly imaginable words, compared to more abstract/less imaginable words.

Welte (1993) examined memory performance in right-handed patients with recent right hemisphere cortical strokes. Of note, subjects with right frontal lobe lesions were not included in this study. Results suggested that story recall test performance (WMS-R Logical Memory) was within normal limits; however, performance on a list-learning task (CVLT) was impaired compared to the normative sample. In particular, it was reported that the right hemisphere stroke patients recalled a smaller percentage of words from end of the list compared to the beginning of the list (i.e., reduced recency effect) and displayed reduced semantic clustering compared to normal subjects. Welte suggested that adequate performance on recall of prose may result from the contextual organization and semantic properties of the story. Welte also proposed that poor performance on the CVLT might have resulted from difficulty visualizing the items from the list or maintaining an adequate level of cerebral activation/arousal.

Similar to Welte's study, Cappa, Papagno and Vallar (1990) also studied learning of verbal information after right hemisphere stroke. Although they found that the right hemisphere stroke patients had relatively intact verbal learning when compared to the left hemisphere stroke patients, when analyzing the serial position curve in free recall trials, they also found a significant reduction in the recency effect compared to left hemisphere stroke patients and controls. Thus, although right hemisphere stroke patients may produce an entirely normal memory span, they appear to demonstrate difficulty selecting organization strategies to most optimally perform the task.

Overall, subjects with right hemisphere strokes perform better than subjects with left hemisphere strokes on measures of verbal memory. Nevertheless, despite intact language functioning, right hemisphere stroke patients show impaired efficiency of learning and memory strategies, especially on verbal list-learning tests, when compared to normal control subjects. Essentially, right hemisphere stroke patients recalled significantly fewer words from the beginning and middle of word lists compared to the end of word lists, and displayed poor efficiency organizing information, as noted on indices of semantic clustering. Further research on the effects of right hemisphere stroke on verbal learning and memory is necessary.

Diencephalic Stroke

In addition to the cerebral hemispheres, the forebrain also consists of the diencephalon. The diencephalon, situated between the brainstem and the cerebral hemispheres, is comprised of the thalamus, epithalamus, subthalamus, and hypothalamus. Of these, the thalamus is the largest and is well known for its extensive reciprocal connections with the cerebral cortex. Lesions to the thalamus often mimic cortical focal deficits due to the richness of the thalamocortical connections, and have been linked with severe memory, attention and "executive functioning" deficits (e.g., Bogousslavsky, Regli, & Uske, 1988; Schott, Crutch, Fox, & Warrington, 2003; Van der Werf, Witter, Uylings, & Jolles, 2000; Van der Werf et al., 2003). Computed tomographic (CT) scans reveal that strokes specific to the thalamus, especially in the anterior, mediodorsal, and midline thalamic nuclei are principally identified in individuals with deficits in memory for verbal information. Connections to the hippocampus, mammillary bodies, amygdala and the frontal role appear to mediate these functions (Crosson, 1992; Graff-Radford, Tranel, Van Hoesen, & Brandt, 1990; Squire, 1990; Van der Werf et al., 2000; Van der Werf et al., 2003; Von Cramon et al., 1988).

The thalamus appears to have a crucial role in encoding and consolidation; however, it may also have a less prominent role in retrieval (e.g., Crosson, 1992; Markowitsch, von Cramon, Hofmann, Sick, & Kinzler, 1990; Parkin, Rees, Hunkin, & Rose, 1993; Van der Werf et al., 2000; 2003). Specifically, thalamic lesions, especially those affecting the mamillo-thalamic tract are related to a slow rate of learning, and thus a deficient encoding. Nevertheless, the rate of forgetting is usually normal. This slow acquisition is possibly related to problems in arousal and organization. In addition, due to poor encoding of information, performance on recognition trials is often poor. Other areas of memory that may be affected include loss of memory strategies, susceptibility to proactive interference, and intrusion errors.

Thalamic functioning appears to produce lateralization effects such that the left side of the thalamus is particularly important for learning verbal information, as well as right sensory-motor functions; whereas, the right side of the thalamus plays a greater role in learning visual material and left sensory-motor functioning (e.g., Annoni et al., 2003; Schott et al., 2003). However, variable patterns of memory disturbance have been reported post-thalamic stroke (Van der Werf et al., 2000; 2003) and further investigation is necessary.

Subcortical Stroke

Although thalamic strokes play an important role in encoding information, strokes in other subcortical regions, including the internal capsule and the basal ganglia, are primarily associated with deficits in retrieval and poor word generation and working memory problems (Markowitsch, et al., 1990; Reed et al., 2000; Tatemichi et al., 1992; Wagner & Cushman, 1992). Functional neuroimaging studies have shown that patterns of metabolism are distinct in this group, with relatively less prefrontal activation noted after subcortical stroke compared to mesial temporal dysfunction (Reed et al., 2000; Strub, 1989; Troyer, Black, Armilio, & Moscovitch, 2004).

The basal ganglia consists of the caudate nucleus, putamen, globus pallidus and amygdala, although the amygdala is located in the temporal lobe and is often considered along with other components of the limbic system. The role of the basal ganglia is widespread, including involvement in various cognitive deficits such as intelligence, memory, and language, as well as aspects of motor functioning such as learning and planning new action sequences. In terms of memory after basal ganglia strokes, deficits range in severity (e.g., Troyer, et al., 2004). Generally, basal ganglia strokes tend to result in primarily retrieval deficits, with recognition ability clearly superior to free recall ability. The role of the basal ganglia in the retrieval of items from a list is especially prominent for items in the middle of the list, which are often thought to be the most difficult to retrieve (e.g. Zhang et al., 2003). Furthermore, less lateralization of memory follows basal ganglia lesions compared to medial temporal lesions.

Overall, the pattern of retrieval deficits after subcortical stroke, particularly in the basal ganglia, is characterized by impaired free recall with relatively better cued recall or recognition. This is similar to the pattern of memory impairment observed in individuals with subcortical dementia due to Huntington's disease, HIV, and Parkinson's disease (e.g., Butters, Granholm, Salmon, Grant, & Wolfe, 1987; Delis et al., 1991; Delis et al., 2000; Kramer, Levin, Brandt, & Delis, 1989; Massman et al., 1990; 1992; Peavy et al., 1994; Squire, 1992).

Cerebellar Stroke

The cerebellum, a region traditionally thought to only be responsible for basic motor control, is now considered to be associated with a number of cognitive functions. Damage to the cerebellum may result in impairments in visuospatial organization, selective attention, working memory, learning, and various "executive functions" (e.g., Lalonde & Botez-Marquard, 2000). It has been hypothesized that the cerebellum assists cognitive functioning at a modulatory level between the execution and actual processing of cognition (Silveri & Misciagna, 2000). The right side of the cerebellum projects to the left cerebral hemisphere, including prefrontal language areas, and has frequently been reported to be involved in verbal tasks, whereas the left side of the cerebellum has been reported to play a role in spatial memory (e.g., Chafetz, Friedman, Kevorkian, Levy, 1996; Marien, Engelborghs, Fabbro, & De Deyn, 2001; Riva & Giorgi, 2000). In patients with cerebellar stroke, the lateralization of verbal and nonverbal functions is not always clearly demonstrated (Fabbro et al., 2004). With regards to verbal memory, deficits are generally limited to poor retrieval of word lists (i.e., deficient free recall in spite of intact cued recall and recognition) (e.g., Appollonio, Grafman, Schwartz, Massaquoi, & Hallett, 1993; Hirono, Yamadory, Kameyama, Mezaki, & Abe, 1991). Appollonio et al. (1993) suggested that memory impairments after pure cerebellar dysfunction appear specific to more effortful tasks, and may be secondary to deficits in initiation and perseveration. Bracke-Tolkmitt et al. (1989) reported that verbal learning deficits in patients with cerebellar damage may not be a generalized deficit, because performance on tests of immediate and delayed story recall is usually intact despite specific deficits to associative learning (e.g., as observed on verbal paired associate tests). Additional study of the effects of cerebellar stroke on verbal list-learning is warranted.

California Verbal Learning Test (2nd Edition) - Short Form

Development of the CVLT-II SF

The development of the CVLT was initially driven by the need to maximize the number of characteristics of memory that could be scored, while basing these aspects of memory processing on principles developed in cognitive neuroscience (Delis, Freeland, Kramer, & Kaplan, 1988). Insight into the neural architecture of memory processes comes mainly from convergent evidence from studies of patients with brain lesions and functional neuroimaging studies.

Rather than explaining memory as a unitary capacity, cognitive neuroscience and information processing approaches assume that memory, similar to other complex cognitive functions, can be subdivided into fundamental subprocesses. Three main processes include (1) encoding, the initial stage which permits information to enter memory, (2) consolidation, which allows for the long-term storage or retention of information, and (3) retrieval, the method allowing stored information to be recovered. Dysfunction at any of these stages may result in memory problems.

Many patients with memory problems primarily demonstrate a deficit in encoding. In accordance with Craik and Lockhart's (1972) "levels-of-processing" approach, it is reported that amnesic patients process information superficially. By not using a deeper, meaning-based analysis, their memory is considerably poorer than found in non-amnesic individuals. The view that memory is dysfunctional due to encoding deficits is verified by studies that demonstrate that patients with Korsakoff syndrome and Alzheimer's disorder, are observed to display an impairment primary in encoding rather than retrieval (Delis et al., 1991).

Some theories suggest that a deficit primarily in retention may be responsible for impaired memory. In 1966, Milner described a post-encoding "deficit in consolidation." This deficit was thought to prevent the transition of memory from a transient short-term memory to a relatively permanent long-term storage. This model recognized that some patients with memory deficit, most notably patients with medial temporal lobe dysfunction, display an unusually rapid rate of forgetting.

Other theorists, including Warrington and Weiskrantz (1970) proposed a theory of "retrieval interference" as a model for amnesia. This theory is based on two main findings: (1) patients with memory impairment often perform better on tests of cued recall than free recall, meaning that although they have encoded the information, they need assistance in retrieving it, and (2) amnesic patients usually have difficulty remembering previously encoded events or facts from before the onset of their amnesia. This is further reinforced by the fact that many patients with impairments in memory, for example those with transient global amnesia or traumatic head injury, regain lost memory as they recover. This suggests that memories must have been efficiently encoded at one time, but retrieval was later hindered.

Clearly, theories of memory based on deficits in encoding, retention or retrieval all have their merits. In addition, the distinction between these processes is undoubtedly useful for the purpose of clinical assessment. Nevertheless, these three processes overlap, and it is not sufficient to look at any one of them in isolation. Rather it should be assumed that memory may result from a dysfunction in any or all of these stages. The dissociation of various memory functions, such that some areas of memory are impaired while others are spared, underscores the fact that the neural underpinnings of various memory functions are clearly distinct.

One method for categorizing memory functions involves distinguishing between declarative and procedural memory. Declarative memory involves the encoding, retention and retrieval of information that can be consciously remembered (Cohen & Squire, 1980). This includes memory for events (episodic) and memory for facts (semantic), and is measured by direct or explicit tests involving recall and recognition (Butters et al., 1987). List-learning tests fall under the category of declarative memory. In contrast, procedural memory (skill learning) involves the acquisition, retention, and retrieval of knowledge expressed through hands on, experience-induced changes (e.g., sensory, perceptual, cognitive or motor skills) (Squire, Cohen, & Zouzounis, 1984). Skills, which can be learned with practice, may include how to ride a bike, drive a car, play an instrument, or use appliances.

Lesions to the diencephalon and medial temporal lobe may result in amnesia, which includes a deficit in declarative memory despite sparing of attention span, working memory, remote memories, and procedural memories (Cohen & Squire, 1980; Drachman & Arvit, 1966). Damage to the hippocampal region, especially involving the CA1 field, is sufficient to produce significant deficits in memory, although involvement of additional medial temporal regions adds to the severity. Different regions appear to be involved in encoding versus retrieval (Delis et al., 2000), although there is debate as to the exact locations of these functions. In addition, lesions to the diencephalon and medial temporal lobe result in extremely quick rates of forgetting compared to healthy individuals. Damage to the neighboring amygdala can add to difficulties in the emotional aspects of memory (e.g., Cahill, Babinsky, Markowitsch, & McGaugh, 1995; Phelps & Anderson, 1997). Patients with amnesia tend to have deficits in ability to learn new information (anterograde amnesia), and often times a loss of information acquired prior to the onset of amnesia (retrograde amnesia). Anterograde and retrograde amnesia are usually temporally graded depending on severity of the injury.

As previously discussed, lesions in the left hemisphere tends to result in deficits in memory for verbal information, whereas lesions in the right hemisphere usually lead to deficits in visual memory (e.g., Milner, 1971). Individuals with language dominance in the right hemisphere show the opposite pattern (Desmond et al., 1995). Global amnesia may occur when both hemispheres are involved. Either unilateral or global amnesia may be evident in patients with temporal lobe epilepsy, temporal lobe resection (as in the famous case of H.M.), herpes simplex encephalitis, Alzheimer's disease, alcoholic Kosakoff's syndrome, and stroke. Although most of these causes of memory impairment may also be associated with additional deficits in cognitive functioning.

Interestingly, individuals with difficulty recalling novel information often have intact recall of remote memories. It is been reported that the neocortical systems are important for the consolidation of long-term memory. Different activation areas, identified in neuroimaging studies, have been shown to be involved the naming of objects, from specific categories (e.g., names of people, tools, animals, or common objects) (Damasio et al., 1996). Disruptions to any of these domains results from extensive, yet specific damage to the neural network involved in a particular domain (e.g., picture naming), which localization often resulting from interaction of different lobes, and thus different perceptual and motor systems.

Other deficits in memory may result from problems organizing information to be remembered. Areas of the brain responsible for strategic memory (i.e., how information is retrieved, manipulated, and transformed), is generally associated with subcortical regions of the brain as well as the dopaminergic fronto-striatal system (Gabrieli, 1996). Deficits in strategic memory are commonly associated with basal ganglia dysfunction, including Parkinson's disease, Huntington's disease. For example, patients with subcortical dysfunction improve on memory tasks when provided with cues, and thus are thought to have intact encoding, but relatively poor retrieval. In addition, patients with memory problems associated with frontal lobe and subcortical lesions are also characterized by errors in memory due to confabulation and diminished insight (O'Connor, Verfaellie, & Cermak, 1995).

Although less relevant to declarative memory processes, a number of other regions are important in memory, such as the cerebellum, which is particularly important in conditioning, and the neocortex, which is especially useful for priming (facilitation or bias in performance that results from prior exposure to some stimuli) (Schacter, Chiu, & Ochsner, 1993). Thus it is clear that the medial temporal lobe is not alone in memory functioning. Further, memory processes are highly interactive, and clear distinctions can be difficult to make.

Just as there are numerous ways to define memory, there are also many ways to measure it. In terms of memory for verbal information, the most frequently used method of assessment includes "list-learning tasks." List-learning tasks have been thought to be particularly useful in studying memory because they allow for the measurement of numerous domains of memory. In addition to the above-mentioned subcomponents of memory (such as encoding, consolidation, and retrieval), list-learning tasks can evaluate learning rate and style, and often times, effects of interference. The list-learning format has become virtually the standard for verbal learning tests as can be seen when examining the Rey Auditory Verbal Learning Test (RAVLT; Rey, 1958), the Hopkins Verbal Learning Test - Revised (Benedict, Schretlen, Groninger, & Brandt, 1998), the Word Lists subtest of the Wechsler Memory Scale – Third Revision (Wechsler, 1997), and the CVLT (Delis et al., 1987; 2000).

Predecessors of the CVLT-II SF, including the original CVLT and the standard form of the CVLT-II, are regarded as a useful tools for characterizing memory profiles associated with various neurological and psychiatric problems including: Alzheimer's disease (e.g., Delis et al., 1991; 2000; Fox, Olin, Erblich, Ippen, & Schneider, 1998; Kramer et al., 1988), subcortical dementia's including Huntington's disease and Parkinson's disease (Buytenhuijs et al., 1994; Massman, Delis, Butters, Levin, & Salmon, 1990), Korsakoff syndrome (Delis et al.,1991), left temporal lobe and hippocampal lesions (e.g., Hermann, Wyler, Bush, & Tabatabai, 1992; Hermann et al.,1994; Hermann et al., 1996), frontal lobe lesions (Hildebrandt et al., 1998), Human immunodeficiency virus (HIV) (Murji et al., 2003; Peavy et al., 1994; Rourke, Halman, & Bassal, 1999), schizophrenia (Hazlett et al., 2000; Paulson, Heaton, Sadek, Perry, & Jeste, 1995), traumatic brain injury (Curtiss, Vanderploeg, Spence, & Salazar, 2001; Deshpande, Millis, Reeder, Fuerst & Ricker, 1996; Millis & Ricker, 1994; Wiegner & Donders, 1999), and depression (Delis et al., 2000; Massman et al., 1992).

List-learning tasks not only allow for identifying an individual's style of learning and memory, but also have important implications for rehabilitation. Appropriate interventions can be aimed at improving processes of attention, encoding, clustering, consolidating, and/or retrieving information. For example, individuals with memory problems resulting from poor attention may need to minimize distractions, individuals with memory problems resulting from encoding difficulties may benefit from repetition of information, and individuals with impaired retrieval may profit from cues to help recall. If memory problems are a combination of these, such as impaired acquisition and retention, additional compensatory strategies are often required. If not compensated for, memory problems may further result in difficulty on higher-level tests (e.g., planning and organizing). In addition, enhancing learning and memory can allow for more rapid progress in therapies (e.g., speech, physical, and occupational therapy), fewer difficulties in regaining independent living skills, and quicker reintegration into the community.

The main goal in the development of the short form of the CVLT-II was to devise a brief, easily administered, test that would be sensitive to subtle impairments in verbal learning and memory. The CVLT-II SF can be administered to individuals 16 to 89 years of age to aid in the diagnosis of various disorders. This measure offers clinicians the prospect of saving half the administration time of the standard form, while reportedly revealing the majority of the critical aspects of an individual's verbal learning and memory. The brevity of this test allows for examination of memory functioning, even in individuals with severe cognitive impairments or susceptibility to fatigue. However, when creating a short form of a test, its usefulness as well as its limitations must be carefully studied.

CVLT-II SF Administration

The CVLT-II SF is a test of learning and memory for verbal information that involves the presentation of a nine-word list, from three semantic categories, (i.e., "fruits," "clothing," or "tools"). The words are presented in a fixed random order at a rate slightly longer than one word per second. The list is presented in four learning trials, and each time the participant is asked to recall as many words as possible in any order. Following the learning trials there is a 30-second delay, at which time the subject counts backward from 100. After this delay, the participant is asked to recall any words they remember from the list (Short-Delay Free Recall Trial). The Long-Delay Free Recall trial is included after a 10-minute delay occupied with other tests, preferably tasks nonverbal in nature. Next, the examiner provides semantic category cues to prompt recall of the list (Long-Delay Cued Recall). Following these trials, recognition memory is tested with a "yes/no" recognition trial that includes 9 target words embedded in 18 distracters. The participant is asked to say "yes" if they believe the word is from the list presented earlier, and "no" if it was not. The number of target words identified correctly (Hits) and the number of false positive items are used to determine recognition discriminability. The number of errors, including Intrusion Errors and Repetitions are also recorded. After an additional five minutes, an optional Long-Delay Forced-Choice Recognition trial may be administered. Overall, this task takes about twenty minutes, including the ten-minute delay, or up to thirty minutes if the forced-choice task is also completed (Delis et al., 2000).

Computer scoring is recommended to convert raw scores into z scores using age- and gender-stratified norms. Three types of reports can be generated by the software including the Core Report, the Expanded Report and the Research Report. Fifty-one normed measures are computed when using the Short Form's Expanded Report, whereas only 15 measures can be easily calculated with hand scoring.

CVLT-II SF Measures

It is important to understand why individual measures of the CVLT-II SF are administered. The following section describes several measures and how they are useful for interpreting different aspects of learning and memory for verbal information. Emphasis is placed on the fact that analysis of scores and clinical findings must be interpreted with caution as examinations of the CVLT-II SF's validity and reliability are in their early stages.

Learning Trial 1. Performance on the first immediate-recall trial is thought to be particularly reliant on auditory attention span (Delis et al., 2000). Considering the hierarchical conceptualization of attention and higher order cognitive abilities, it is speculated that an intact attention span is necessary, although not sufficient, for optimal verbal learning on the subsequent trials. Interestingly, on the first learning trial of the standard form of the CVLT-II, the normative reference group recalled an average of 6.6 target words. This corresponds to classic studies by Miller (1956), who states that a person's initial ability to repeat information is limited to seven plus or minus two "chunks" (digits, letters, or words) of information.

Poor performance on this measure may not necessarily result from poor memory, but rather it may result from low attention or concentration due to poor arousal, variable motivation or depressed mood (e.g., Kizilbash, Vanderploeg, & Curtiss, 2002). Of note, individuals with impaired attention often show improvement across learning trials due to intact learning and memory. In contrast, individuals with intact performance on Learning Trial 1 may later display impaired ability on subsequent learning trials because they are unable to incorporate information beyond their basic attention span. This pattern has been documented in patients with severe hippocampal dysfunction (Delis et al., 2000), and appears to support models suggesting distinct short-term and long-term memory systems. For example, Baddeley's (2003) model suggests that the phonological loop component of working memory, likely served by the dorsolateral prefrontal cortex, operates independently of memory systems in the medial temporal lobe.

Delis, Cullum, Butters, Cairns, and Prifitera (1998) reported that the first learning trial of the original CVLT correlates robustly with the number of digits recalled in the forward portion of the WAIS-R Digit Span subtest. However, although both of these measures appear to test immediate auditory attention, there are significant differences between these tests. For example, digit recall may be less overwhelming than tests of word list recall, because digit recall tests such as the Wechsler Digit Span subtests are presented with gradually increasing difficulty level, whereas on list-learning tasks, the entire list is presented from the onset of the test. In depth examination of the Learning Trial 1 of the CVLT-II SF, and its ability to assess immediate auditory attention, is necessary.

Learning Trials 2 to 4. When provided with the opportunity to learn a list of words by means of numerous trials, performance in healthy individuals is likely to exceed their attention span (i.e., seven plus or minus two words). Auditory attention is no longer the primary domain of functioning at work. Encoding into long-term memory and retrieval (bringing stored information into conscious awareness) from long-term memory are also important abilities necessary to perform Learning Trials 2 to 4 at an adequate level (Delis et al., 2000).

Total score from Learning Trials 1 to 4. Combining the scores from Trials 1 to 4 allows for the calculation of a global index of verbal learning ability (Delis et al., 2000). Standard scores can be calculated for the total number of words recalled across the learning trials, as well as for each of the individual learning trials, allowing clinicians to assess patterns of learning which may reflect specific neurological disorders.

Learning Slope. The CVLT-II SF allows for calculation of learning slopes, which provide measures of the average number of new words an individual recalls per trial (Delis et al., 2000). A significant improvement in words recalled from the first learning trial to the second learning trial (Learning Slope Trials 1-2), is sometimes suggestive of poor attention or mood issues such as test anxiety (Delis, 1989). A significant improvement noted when comparing trials one and four (Learning Slope Trials 1-4) or trials two and four (Learning Slope Trials 2-4) usually suggests adequate learning, whereas quickly reaching a learning plateau may be suggestive of an encoding deficit.

Short-Delay Free-Recall Trial. After a short delay, at which time the subject counts backwards from 100 for 30 seconds, the examiner requests the list to be recalled without re-presenting the list. A decrement relative to Trial 4 may result because of the short time delay, and may indicate the degree of forgetfulness. A retention score is calculated by subtracting the standard score on Trial 4 from the standard score on Short-Delay Free-Recall Trial. Impaired recall with normal retention is characteristic of several disorders including, damage of primarily subcortical structures (e.g., Parkinson's disease, Huntington's disease, multiple sclerosis, and HIV infection) (Delis et al., 1991, 2000; Massman et al., 1990, 1992). In contrast, patients with Alzheimer's disease, Korsakoff syndrome, or left-temporal/hippocampal damage, may show considerable impairment in retention rates compared to recall (Delis et al., 1991, 2000; Hermann et al., 1996; Hildebrant, Brand, & Sachsenheimer, 1998).

Long-Delay Trials. Long-term storage problems are common in neurologically impaired patients; therefore, the Long-Delay Trials may provide useful information (Delis et al., 2000). The long delay trials are administered after a 10-minute delay, which does not involve testing of verbal functioning. Administration is similar to the Short-Delay Free-Recall Trial, and often performance is comparable. Following the Long-Delay Free-Recall trial, a Long-Delay Cued-Recall trial is administered. The examiner presents the three categories (i.e., "fruits," "clothing," and "tools"), requiring subjects to use a semantic clustering technique. Often, this leads to a higher raw score than observed with Short-Delay Free-Recall, suggesting that more words were encoded than could be retrieved (Delis et al., 2000). In some cases, cues may make those prone to confabulate, amplify their rate of intrusions (Delis et al., 1991). Usually, if both free and cued recall are impaired, then problems in encoding may be the source of the examinee's memory dysfunction.

Semantic, Serial, and Subjective Clustering. Effective organization is related to the amount of verbal information that is learned (e.g., Delis, Freeland et al., 1988). In order to interpret learning patterns or encoding strategies utilized, the CVLT-II SF includes measures to analyze styles of clustering (Delis et al., 2000).

Consecutive recall of items from a semantic category reflects the examinees ability to actively reorganize the list according to shared semantic features, therefore allowing efficient encoding into and retrieval from long-term memory. Low semantic clustering scores may correlate with poor performance on the other indices, suggesting that the examinee is utilizing less efficient learning strategies.

"Serial clustering" refers to recall of words in the order in which they were presented by the examiner. Serial clustering often reflects a deficient memory performance, characterized by a "stimulus-bound" style of recall, in which the individual adheres rigidly to temporal order, failing to recognize words semantically. However, interpretations of this measure may be modified when considering the context of additional background information and performance. For example, there may be situations in which serial clustering is representative of superior memory skills. This can be illustrated by an individual with a strength in memory skills, who attempts to recall words in the order of presentation to make the task more challenging.

Other individuals may use a strategy based on idiosyncratic methods of clustering, termed "subjective clustering." For example, this may result from mnemonic techniques including, forming interactive visual images involving pairs of words.

Of importance, calculation of clustering indices is adjusted using a subtraction method to take into account clustering that occurs by chance. As there is limited research on the CVLT-II SF, it is not yet understood if measures of clustering provide effective understanding of organizational styles considering that the number of words in each category is limited.

Recall from primacy, middle, and recency regions. Individuals typically recall more words from the beginning and end regions of a list compared to middle regions. Recency effects (recalling the last words on the list) and primacy effects (recalling the first words on the list) can occur with varying degrees of semantic or serial clustering. The "serial position effect," described in detail by Murdock (1962), suggests that words correctly recalled from the end of a list result from short-term storage, whereas words recalled from the beginning of a list might be accessed by means of a long-term storage mechanism. Others have speculated that the greater difficulty associated with recall of items from the middle of the list is related to temporal interference (e.g., Zhang et al., 2003). Average to above-average recall on words from the primacy and middle regions has been associated with good long-term memory, whereas recall of only words from the recency region may reflect the individual's tendency to merely echo back words rather than encoding them into long-term memory. Of note, studies of "pure" recency and primacy effects should be restricted to observations of performance on the first trial because once the list is presented multiple times deficits may result from impairments in retrieval from long-term memory, therefore it becomes difficult to associate primacy with long-term memory or recency with short-term memory (Massman, Delis, & Butters, 1993).

Intrusion and Repetition Errors. The number of non-target words reported during the free- and cued- recall trials are recorded as intrusion errors (Delis et al., 2000). The number of target words that are repeated are recorded as repetition errors (note these were called "perseveration errors" on the original version of the CVLT) (Delis et al., 1987). Errors may be a result of confabulation in the case of subjects with poor encoding ability, or perseverations. It is important to distinguish between repetition errors, and responses that reflect techniques used to self-cue.

Recognition Trial. To test recognition memory, the CVLT-II SF uses a list of words containing the 9 words originally presented, plus 18 distracters (Delis et al., 2000). Distracters include words from the same semantic categories as the words in the original list, as well as unrelated words. Phonemically similar items (e.g., "tires" compared to "pliers") are not included because this creates unnecessary difficulty for patients with hearing impairments. Similar to intrusions, a high rate of false-positives (responding "yes" on distracter words) may be associated with serious memory impairment (Delis et al., 1991, 2000). Because false-positives inflate the rate of "Hits," the number of

Recognition Hits should not be interpreted on their own. The Discriminability index is the best measure of overall recognition performance because it takes into account both the number of "Hits" and the rate of "False-Positives." A low discriminability scores may indicate a difficulty in differentiating target items from distracter items, thus suggesting an encoding deficit may contribute to the examinee's memory problems.

Recognition versus Long Delay Free Recall. Individuals scoring high on the Recognition Trial but poorly on free recall trials are thought to have a deficit in retrieval (Delis et al., 2000). In contrast, individuals scoring equally poorly on both recognition and free recall are thought to have deficits primarily of encoding. Another pattern, which includes both deficient encoding and retrieval, is reported when both recognition and recall are impaired, but free recall is significantly worse. A pattern characterized by a significantly worse recognition discriminability score compared to free recall score is rare, and may warn the examiner to assess motivation. These patterns can be examined by inspecting Recall/Recognition contrast scores (e.g., z score of the Long-Delay Cued-Recall trial is subtracted from the z score of the Total Recognition Discriminability versus). Individuals with predominantly subcortical dysfunction are inclined to have high contrast scores (generally a standard deviation score of +1, if not better) suggesting that significant improvement in made when recognition cues are available (Delis et al., 1991; Massman et al., 1992).

Force-Choice Recognition. An optional force-choice recognition trial is administered 5 minutes after the completion of the recognition trial. Impaired performance on this trial may be suggestive of poor effort; however, on the short form this variable is primary used to assess the upper limits of residual memory in individuals with severe cognitive impairments.

Technical Aspects of the CVLT-II SF

Thus far, psychometric information on the CVLT-II SF is extremely limited. Norms for this measure were developed by means of calibrating raw scores on the CVLT-II SF with those on the CVLT-II standard form using equipercentile equating (Delis et al., 2000). This equating study was based on the scores of 278 subjects who were administered both the standard and short forms in a counterbalanced order.

In addition, to developing norms for the CVLT-II SF, the predictive ability of the CVLT-II SF has been investigated. Taneja, Rourke and Hanks (2004) examined the relationship between performance on the CVLT-II SF and ability to perform activities of daily living (based on the Functional Independence Measure) in a sample of inpatient stroke survivors at an urban rehabilitation hospital. Results indicated that after admission functional outcome scores were controlled for, the CVLT-II SF (total score from Trials 1 to 4) was found to be predictive of functional outcome scores at discharge. Not surprisingly, the CVLT-II SF's ability to predict improvement in functioning was significantly better for cognitive tasks than for self-care and mobility. Other than this, there are no known published studies examining the CVLT-II SF. As psychometric properties of the CVLT-II SF are still under investigation, the following section briefly touches on the reliability and validity of the original CVLT and the standard form of the CVLT-II.

"Reliability refers to the extent to which multiple independent assessments of the same (clinical) phenomena can be substituted, one for the other; or, put another way, the extent of replicability, or duplicability of independently derived measurements" (Cicchetti & Rourke, 2004; p. 17). Reliability of the CVLT and CVLT-II is adequate when tested by means of measuring test-retest and parallel forms methods (Delis et al., 1988; 2000). Similarly, the internal consistency of the total scores on the learning trials has been high, largely above 0.90, for both a non-neurologically impaired and a mixed clinical sample (Delis et al., 1988; 2000).

It is important to understand the meaningfulness or interpretability of test scores. A test is considered to be valid, if it measures what it was designed to measure. Validity studies of the original CVLT have revealed moderate to high correlations between the CVLT and other measures of memory. This suggests that the CVLT demonstrates adequate convergent validity (Delis et al., 1988). When comparing performance on the CVLT and AVLT mean raw scores do not differ significantly; however, standard scores calculated from norms have shown to be significantly lower on the CVLT (Crossen & Wiens, 1994; Stallings, Boake, & Sherer, 1995). Similar discrepancies between standard scores have been observed when comparing the CVLT to the Wechsler Memory Scale – Revised (Randolph et al., 1994). In addition, Macartney-Filgate and Vriezen (1988) have reported modest correlations among selected scores between the CVLT and the Verbal Selective Reminding Test (VSR; Buschke, 1973).

As the above studies reveal, a major complaint with the original CVLT was that is did not appear to be properly standardized and norms were grossly inflated (Elwood, 1995). Norms in the CVLT manual and scoring system frequently misclassified individuals by exaggerating impairments. It is likely that discrepancies between standard scores of various verbal learning tasks and the CVLT resulted from a high proportion of well-educated individuals used in its normative reference sample. These issues are reportedly resolved for the standard form of the CVLT-II, which was normed based on 1087 adults matched to the U.S. Census in terms of demographic variables.

In addition, it must be warned that the CVLT also correlates significantly with a number of other neuropsychological measures (Woodward, Hancock, Pennell, & Henry, 1996), whereas other tests of memory, including the Logical Memory I and II from the Wechsler Memory Scale, correlate well with measures of memory but not significantly with other neuropsychological tests. This leads one to speculate that the CVLT may in fact be a measure of overall neuropsychological functioning rather than a tool specific to verbal memory deficits.

Validity of the CVLT has been discussed in terms of performance with various neurological groups. Studies show that the original CVLT is useful for several populations including: chronic alcoholics, patients with Parkinson's Disease, Multiple Sclerosis, Huntington's Disease and Alzheimer's Disease (Delis et al., 1987; Fenton, 1998). Interestingly, a German version of the CVLT has been shown to adequately discriminate between individuals with left temporal, left prefrontal, and right parietal strokes; although documentation of the English version's utility for differentiating between subgroups of stroke is not currently available in the literature.

A test's factor structure is an important aspect of its construct validity. Since the development of the original CVLT, several studies have investigated the nature of its constructs by means of factor analytic methodology. Delis, Freeland, Kramer and Kaplan (1988) used a principal component analysis with 286 control subjects and 113 mixed neurological subjects. When analyzing data from the control sample, Delis et al. were able to derive 6 factors from 19 CVLT variable including: 1) general verbal learning, 2) response discrimination, 3) learning strategy, 4) proactive effect, 5) serial position, and 6) acquisition rate. For the neurological sample five comparable uncorrelated factors were identified.

Millis and Ricker (1994) noted that the CVLT had been frequently utilized to assess memory in subjects with traumatic brain injury. However, given the diverse nature of brain injury, Millis and Ricker were interested in examining if the CVLT could also be used to identify differential patterns of performance among groups of traumatic brain injury patients because prior to this, studies generally focused on the global impact on memory impairment rather than the various components of memory processing. In Millis and Ricker's study, cluster analysis of selected CVLT variables was used and from an initial group of 65 traumatic brain injury patients, four distinct subtypes of learning and memory performance were generated. These were identified as: 1) active, 2) disorganized, 3) passive, and 3) deficient.

Replication with traumatic brain injury patients yielded similar results (Deshpande, Millis, Reeder, Fuerst, & Ricker, 1996; Haut & Shutty, 1992; Wiegner & Donders, 1999). For example, Wiegner and Donders (1999) investigated the performance of 150 brain-injured patients on the CVLT. Using cluster analysis, the sample could be divided into reliable subtypes. The first group displayed significantly below average scores on all variables, scored poorer on WAIS-R Full Scale IQ and Part B of the Trail Making Test and correspondingly suffered severe injuries with longer length of coma than the second group who displayed average CVLT scores and milder TBI. Thus, results indicated that the CVLT is sensitive to general severity of TBI. In general, Wiegner and

Donders suggested that the sequelae of TBI patients are not expressed in a unitary pattern. However, the best fitting model for the underlying latent structure of the CVLT in this sample can be represented by four-factor model composed of (1) Attention Span, (2) Learning Efficiency, (3) Delayed Recall, and (4) Inaccurate Recall. Difficulties with Attention Span are represented by poor performance on the immediate repetition of information presented only once. Learning Efficiency problems may result from difficulty with actively and efficiently employing processing or mnemonic strategies (List A5; semantic clustering ratio for List A, Trials 1-5; percent correct words recalled from recency region of List A Trials 1-5; and percent of correct words consistently recalled across consecutive presentations of List A). Delayed Recall was impaired on short and long-term variables, as well as both free and cued. Inaccurate Recall was correlated with difficulty discriminating relevant from irrelevant information (total number of free recall intrusions; total number cued recall intrusions; false positives).

Variants of these factor have been found in studies replicating the initial analyses with health job applicants (Wiens, Tindall, & Crosson, 1994), temporal lobe epilepsy patients (Baños et al., 2004) , and HIV infected patients (Murji et al., 2003).

Libon, et al. (1996) designed and examined the validity of a nine-word “dementia version” of the original CVLT. Libon et al. administered the list to 124 subjects, in three groups, including subjects with dementia due to Alzheimer’s disease, subjects with dementia secondary to white matter disease, and elderly, healthy control subjects (with Mini Mental Status Exam scores greater than 27/30). Principal component analysis was used to assess the validity of the nine-word list on non-demented subjects. A three-factor solution resulted with separate factors related to immediate free recall, delayed recall and recognition, and intrusion errors. Unlike the previous mentioned factor analysis studies that used the original CVLT, in this study there was no factor derived that was associated with learning strategy. Construct validity was also assessed by comparing the performance of the three groups of subjects. Healthy control subjects did better on the CVLT across all indices than the two dementia groups. The group with white matter disease generally performed better than the Alzheimer's disease group, obtaining higher scores on indices of delay free and cued recall, retention, and recognition discriminability. Subjects with Alzheimer's disease generally displayed poor retention, rapid forgetting, showed little benefit from cueing, and made many intrusion errors. The authors concluded that the nine-word CVLT has good psychometric properties and appears to be a useful tool to use with patients with obvious memory impairments.

Overall, results obtained by Libon et al. (1996) are similar to findings with the CVLT and CVLT-II, suggesting that the nine-word CVLT can differentiate between subjects with Alzheimer's disease and dementia due to ischemic changes. Despite its reported usefulness, the nine-item version of the CVLT is not identical to the CVLT-II SF. The nine-word CVLT maintained the "shopping list" style of the original CVLT, an interference list (List B), and the short-delay cued recall trial. Additionally, the nine-word list's recognition trial contained intrusions from the interference list, and thus a measure of source memory. Therefore, it is not possible to make any direct comparisons between research on the nine-word CVLT and the CVLT-II SF.

There has been criticism of factor analytic studies stating that overly generous criteria were used for factor retention resulting in a magnified number of factors (e.g., Elwood, 1995). Generally, the prominent factor, accounting for much of the variance, has been a general verbal learning factor, with a number of other factors accounting for a significantly smaller amount of the variance. A study by Gardner and Vrbanic (1998) exemplifies the utility of the general verbal learning factor, while minimizing the importance of other factors described in the factor analysis literature.

Gardner and Vrbancic (1998) examined the CVLT factor structure in moderate to severe TBI patients to determine which factors could discriminate between TBI (n=93) and normal controls subjects (n=80). Rather than using factor analysis, Gardner and Vrbancic analyzed six factors, originally described by Millis (1995), using three backward-elimination logistic regression analysis. These factors included: 1) General verbal learning (Total trials 1-5), 2) Response discrimination (Recognition false positives), 3) Learning strategy (Serial Clustering), 4) Proactive effect (List B recall), 5) Self-monitoring/Learning strategy (Perseverations), and 6) Serial position (Percent recency recall). Results indicated that only the general verbal learning factor (Total trials 1-5) significantly discriminated the moderate and severe head injury group from the normal controls. Overall, they indicated that the correct classification using the total score from trials 1-5 ranged from 84 to 88%. Gardner and Vrbancic suggested that other CVLT variables may be less than optimal predictors of the characteristics of memory functioning that they allegedly symbolize.

In one of the studies by Millis (1995), who obtained a 6 factor model when analyzing CVLT performance in individuals with traumatic brain injury, reported that only the General Verbal Learning Factor significantly correlated with other neuropsychology measures (e.g., memory, complex attention, and strategy induction). Millis suggested additional factors may represent statistical artifacts rather than distinct aspects of memory. Nevertheless, factors representing attention, delayed recall, and inaccurate recall are quite consistently reported in many factor analysis studies. With the development of the second edition of the CVLT, Delis et al. (2000) have replicated their original CVLT factor analysis, obtaining comparable factors. Further investigation of the external validity of various factors identified by the CVLT-II is still necessary. Factor analysis studies using the CVLT-II SF would also be of interest.

List-learning tests were originally designed to avoid the interpretation of global measures of memory. Specifically, the perspective that guided the early development of the CVLT suggested that individual variables should be indicative of quantifiable aspects of diverse memory processes. Thus, although factor analysis can be employed to yield mathematically formulated constructs, it is still necessary to examine the individual variables that comprise list-learning tests (Delis et al., 2000). Likewise, investigation of the CVLT-II SF variables, and the memory components they purportedly represent, is required.

Statement of Purpose

Rationale

The standard forms of the CVLT and the CVLT-II measure multiple verbal learning and memory constructs and have demonstrated clinical utility for characterizing different memory profiles associated with a variety of clinical populations (Delis et al., 1991; 2000). Considering that the CVLT-II SF includes many of the same variables found in the standard forms, it is reasonable to assume that it will show a similar capacity to detect differential patterns of learning and memory for verbal information.

The CVLT-II SF is widely used as a clinical measure, and appears to be especially valuable in situations where cognitive compromise is moderate to severe, or time constraints are a matter of concern. The CVLT-II SF is designed to distinguish between problems with encoding, learning rates, retention over time, and other memory impairments (Delis et al., 2000). It also purports to identify learning strategies employed and types of errors made. Despite the appeal of this quick and easy to use measure, published studies on the utility of the CVLT-II SF are limited.

With the development of a new assessment tool, neuropsychologists must examine the psychometric properties, and reflect on the limitations and benefits of its use. With an abbreviated test, there are added uncertainties, because the test may sacrifice its integrity when compared to the original measure. Based on the literature it is not clear if it the CVLT-II SF provides necessary and sufficient information to distinguish between groups of individuals thought to exhibit different styles of learning and memory for verbal information. Reduction in the length of the target list and elimination of an interference list (List B) and the Short-Delay Cued Recall Trial may leave significant gaps in the information supplied by the test. Research is necessary to understand how well this measure evaluates the ability to learn and remember verbal information, what populations it applies to, and what its limitations are.

Focal vascular lesions have been especially important in understanding neuroanatomical correlates of cognitive functions, and can be useful to foster the growth of knowledge about assessment tools used to understand brain functions. Due to the heterogeneity of the neuropathologial sequelae in stroke, it is not surprising that neuropsychological profiles are often quite distinct depending on lesion location.

Similarly, investigations of profiles of memory in patients post-stroke have reported varied performance depending on the severity and location of the infarct (e.g., Hildebrandt et al., 1998; Tatemichi et al., 1994). Thus, it is evident that samples of stroke patients, especially those with focal infarcts, are useful to aid in the growing knowledge about brain-behaviour relations. It is also clear that tests that intended to differentiate memory patterns among different patient populations should be sensitive to these documented differences.

The purpose of the present investigation is therefore to evaluate the utility of the CVLT-II SF in a sample of rehabilitation inpatients with stroke. Specifically, the goal of this study is to examine the utility of this list-learning test by analyzing its psychometric properties and subsequently determining whether performance patterns on this measure can differentiate between three subgroups of stroke patients: (1) left cortical infarction, (2) right cortical infarction, and (3) subcortical infarction. It is expected that even though the CVLT-II SF is a brief screen of verbal learning and memory functioning, it should nevertheless display adequate psychometric properties and be able to differentiate between the groups. Based on this information, the following hypotheses are put forward.

Hypotheses

Internal Consistency of the CVLT-II SF.

In this investigation, the adequacy of the CVLT-II SF's internal consistency will be measured for the four list-learning trials and the recognition trial. In terms of the learning trials, it is useful to examine the total trial scores rather than individual items due to a problem with item interdependence; for example, a word recalled on one learning trial it is more likely to be recalled on a subsequent learning trial than a word that was not initially recalled.

Internal consistency is thought to be poor if the size of the correlation is less than 0.70, and it is thought to be excellent if it is greater than 0.90 (Cicchetti & Rourke, 2004). The current sample consists of a heterogeneous group of stroke patients, and as measures of internal consistency are sensitive to sample variability, the internal consistency estimates are likely to be lower than correlations expected from a healthy, and more homogeneous normative sample. Nevertheless, it is hypothesized that the internal consistency of the learning trials and items from the recognition trial will be acceptable. Understanding internal consistency, or homogeneity of measures, is important when subsequently examining if the test does what it alleges to do.

Validity of the CVLT-II SF.

The CVLT-II SF is designed to measure various aspects of learning and memory for verbal information. To demonstrate construct validity, it is necessary to show that the CVLT-II SF correlates highly with tests known to assess learning and memory and not with tests that tap other cognitive functions. In order to examine the convergent and discriminant validity of the CVLT-II SF, performance on selected CVLT-II SF indices will be compared to performance on other measures of neuropsychological functioning. It is expected that the CVLT-II SF indices will be significantly correlated with measures of basic attention and episodic memory measures. It is also predicted that the CVLT-II SF indices should have higher correlations with measures of basic attention and memory for verbal information than with other neuropsychological measures, including tests of visuospatial ability, verbal concept formation, and cognitive set-shifting ability.

Differentiating Between Subgroups of Stroke.

Patients with varied stroke pathology are known to demonstrate distinct profiles of memory impairment. This should be reflected by performance on the CVLT-II SF. In the current study, the utility of the CVLT-II SF in differentiating between individuals with left cortical stroke, right cortical stroke and subcortical stroke will be investigated. In general, individuals with left cortical strokes often demonstrate difficulties encoding verbal information, and therefore this group is expected to show the most severe impairments on the CVLT-II SF. Right cortical strokes are associated with relatively intact learning and recall of verbal material, with the exception of some difficulties organizing the information to be learned. Therefore, the group with right cortical strokes should demonstrate the least impairment on the CVLT-II SF. Finally, individuals with subcortical strokes often display intact ability to encode verbal information, but show deficits in information retrieval. For that reason, it is expected that the subcortical stroke group will perform better than the left cortical stroke group but worse than the right cortical stroke group on most indices of the CVLT-II SF. Based on these ideas, a number of hypotheses are put forward:

1. On the immediate learning trials thought to represent immediate auditory attention (Learning Trial 1) and overall verbal learning (Total Score from Trials 1-4), the group with right hemisphere strokes are expected to obtain the highest mean scores, followed by the group with subcortical strokes, and the group with left hemisphere strokes are expected to obtain the lowest mean scores. A similar pattern of performance is expected on the delayed recall free recall trials (e.g., Long Delay Free Recall).

2. When examining learning styles, the cortical stroke groups are expected to have more inefficient learning strategies than the subcortical stroke group. Specifically the cortical groups, left more so than right, are expected to recall more words from the end of the word list than the beginning and middle sections of the list. Therefore, it is hypothesized that the left cortical group, followed by the right cortical group will recall a higher percentage of words from the "recency" region of the list when compared to the subcortical group. The more efficient learning strategies of the subcortical group should also be evident in ability to group words that are semantically related. Therefore, it is hypothesized that the subcortical stroke group will obtain higher scores on the "Semantic Clustering" measure than the left and right cortical stroke groups. Also, the subcortical group should benefit the most from "yes/no" recognition cues. Specifically, it is hypothesized that the subcortical group is expected to obtain the highest scores on Total Recognition Discriminability, whereas the left cortical group is expected to perform relatively poorer on this measure, due to a low number of recognition hits and a high number of false positive errors. Similarly, when examining the contrast between recall and recognition ability (i.e., Total Recognition Discriminability versus Long Delay Free Recall), the subcortical stroke group is expected to receive the most benefit from the "yes/no" cues, followed by the right cortical stroke group. The left cortical stroke group is not expected to make significant gains in recall ability even with cues, thus their recall/recognition contrast score are expected to be the lowest.

3. As a result of performance on individual measures of the CVLT-II SF, collectively CVLT-II SF variables are expected to be useful in predicting membership in one of the three stroke groups. Of the CVLT-II SF indices analyzed, it is expected that the total score from learning Trials 1-4 will be the best predictor of membership in the left cortical, right cortical, and subcortical stroke groups. Most importantly, the set of predictors are jointly expected to accurately classify individual cases into one of the three stroke groups.

METHODS

Participants

Archival data for this study was obtained via chart review from the Rehabilitation Institute of Michigan (Detroit, MI) following Institutional Review Board approval. The data used in this retrospective study consists of patient information obtained during admission to an inpatient stroke rehabilitation unit. Inclusion is based on the following selection criteria: (1) a medical diagnosis of ischemic stroke determined by the attending physician (based on history, clinical examination, and neurological findings), (2) referral for comprehensive neuropsychological evaluation, (3) no prior or concurrent diagnosis of traumatic brain injury, learning disability, or psychosis, (4) English as the primary and first language, (5) complete demographic data and CVLT-II SF, and (6) neuroimaging reports confirming membership into either left cortical, right cortical and subcortical stroke. Individuals with strokes in the brain stem, cerebellum and diencephalon are not included. To determine if the subjects with cortical lesions can be differentiated from those with subcortical lesions, it is important to exclude individuals with evidence of infarction in both subcortical and cortical areas. Likewise, individuals with cortical strokes affecting both left and right hemispheres are excluded. In addition, stroke patients with remote infarcts are excluded if neuroimaging reports reveal that the old infarct is observed in a location different from the recent stroke (e.g., an individual with evidence of a recent infarct in the right temporal region and a remote infarct in the left temporal region is not included as there may be dysfunction in both cortical hemispheres). This study focuses on stroke patients with ischemic strokes, and thus individuals with hemorrhagic strokes are not included.

Procedures

Neuropsychological tests were administered by a staff neuropsychologist or trained psychological technician in a standard fashion as part of a comprehensive evaluation. Patients were seen during the acute phase of their recovery (i.e., less than two months following their most recent stroke). Demographic and medical information were collected by a multidisciplinary team including: physiatry, neuropsychology, nursing and physical, occupational, and speech therapists. For the purpose of this study, the above information was available through review of each patient's medical chart.

Measures

Neuropsychological Tests

California Verbal Learning Test – Second Edition – Short Form (CVLT-II SF).

The current study evaluates the psychometric properties of the CVLT-II SF, an abbreviated measure of learning and memory for verbal information. This individually administered test contains a list of nine words from three semantic categories. The word list is presented across four learning trials. The subject recalls the words immediately after presentation, after short and long delays, and on a recognition trial. Patterns of performance, including errors, are recorded. A detailed description of this test is provided in the introduction of this paper. To examine construct validity of the CVLT-II SF, additional neuropsychological measures are included in this study.

Measures to Examine Convergent Construct Validity of the CVLT-II SF.

Convergent construct validity is examined by comparing the CVLT-II SF scores with performance on neuropsychological tests that measure similar domains of cognitive functioning including immediate auditory attention, and immediate and delayed memory for verbal information. The specific tests included in this study are described below.

The Wechsler Adult Intelligence Scale – Third Edition (WAIS-III; Wechsler, 1997) Digit Span subtest is a measure of immediate auditory attention that requires recall of a series of digits in the forward and backward direction (Wechsler, 1997). For the current study, the highest number of digits recalled in the forward direction was included as a measure of verbal attention span.

The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph, 1998) Story Memory subtest requires immediate and delayed recall of narrative information presented orally. The total scores from the immediate recall of a short story (Story Memory I) and the delayed recall the same story (Story Memory II) are included in the following study as measures of immediate and delayed memory for verbal information.

Measures to Examine Discriminant Construct Validity of the CVLT-II SF.

Selected measures shown to assess domains quite different from memory, basic attention or simple verbal output, are included in this study to examine discriminant construct validity of the CVLT-II SF. Measures of verbal concept formation, visuospatial discrimination, and cognitive set-shifting ability, are described below.

The Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) Similarities subtest requires the examinee to describe the similarities between two words presented orally. The total raw score from this subtest is included as a measure of verbal concept formation or verbal abstraction.

The Line Orientation subtest of the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph, 1998) is a measure of visuospatial discrimination that requires choosing a match for a line segment from an array of lines presented at varying angles. The total number of correctly identified angular relationships is included in this study as a screening measure of visuospatial perception.

The Oral Trail Making Test Part B is a measure of divided attention that requires speeded alteration between numbers and letters progressively (e.g., "1, A, 2, B, 3, C, until reaching the number 13) (Ricker & Axelrod, 1994). The administration of this task follows the administration of Part A, a measure of processing speed, in which the examinee is timed as they quickly count from 1 to 25. The oral version of the Trail Making Test eliminates the spatial-perceptual and motor components that are important for successful performance on the more commonly administered written version of this task. The total time to complete the Oral Trail Making Test Part B was included in the following study as a measure of cognitive set-shifting ability.

Statistical Analyses

Archival data from subjects assessed at the Rehabilitation Institute of Michigan was inputted into a database, and data analysis was completed using SPSS 11.0. For all analyses, a significance level of $p < .01$ is used.

Descriptive Statistics

The stroke sample is divided into groups based on infarct location as indicated by neuroimaging reports (i.e., left cortical, right cortical, and subcortical). Descriptive statistics, including means and standard deviations for demographic information and stroke characteristics are computed. One-way between groups ANOVAs are used to determine if the groups were matched on age, education level, single-word reading ability, and severity of stroke.

Internal Consistency of the CVLT-II SF

Coefficient alpha, the most commonly used measure of internal consistency, is used to analyze the internal consistency of the four learning trials (Cronbach & Meehl, 1955). This is followed by a Spearman Brown split-half correlation, the most appropriate method to examine the learning trials because of an expected upward trend in the average scores across the learning trials (Anastasi, 1982). For the split-half method, an odd-even correlation is calculated; scores from Trial 1 and Trial 3 are summed and compared to the combined score from Trials 2 and 4. Similar methodology was used by Delis et al., (1989, 2000), in the examination of the internal consistency of the standard forms of the CVLT and CVLT-II.

To analyze inter-item consistency, or in other words if items on the recognition trial measure the same concept, a Kuder-Richardson formula 20 (KR-20) coefficient is calculated. The KR-20 is a useful test for this purpose because it provides a conservative or safe estimate of the internal consistency of a set of test results. In addition, it is the most appropriate method for use with test items that scored dichotomously, as is the data in the recognition trial of the CVLT-II SF. Prior to the analysis, all 27 items on the recognition trial were scored for each case and entered into a database according to if the item was answered correctly or incorrectly.

Validity of the CVLT-II SF

Scores from the CVLT-II SF indices and other neuropsychological tests are entered into a correlation matrix to better understand the relationship between variables.

Measures of the CVLT-II SF included for analysis are the first learning trial (reported to be indicative of immediate auditory attention), the total score from the list-learning Trials 1 to 4 (reported to be reflective of immediate recall of verbal information), and the Long-Delay Free-Recall variable (reported to be a measure of delayed recall of verbal information). To examine convergent validity, additional measures of immediate auditory attention (WAIS-III Digit Span score – highest number of digits recalled in the forward direction) and memory for immediate verbal recall (RBANS - Story I) and delayed verbal recall (RBANS - Story II) are entered into the correlation matrix. To assess discriminant validity of the CVLT-II SF, tests thought to assess different neuropsychological domains are also included in the correlation matrix, including a measure of verbal concept formation (WASI Similarities), a measure of visuospatial discrimination (RBANS Line Orientation), and a measure of cognitive set-shifting ability (Oral Trail Making Part B).

Using the CVLT-II SF to Distinguish Between Subgroups of Stroke

Subjects are divided into three groups based stroke location as evidenced in neuroimaging reports (i.e., left cortical, right cortical, and subcortical). To test the main hypothesis, a standard (direct) discriminant function analysis is performed to determine whether or not performance on CVLT-II SF indices can be used to predict membership in the left cortical, right cortical, and subcortical stroke groups.

Because the CVLT-II SF includes several indices, several a priori criteria are used to select CVLT-II SF variables to be included in statistical analysis. Only CVLT-II SF variables with computable standard z-scores based on age and gender are included in this study. To maximize the unique predictive contribution of each variable, those that are highly interdependent are avoided. Also, variables thought to be strongly interdependent based on past literature are not included, for example, although the CVLT-II SF provides standardized scores for three delayed-recall indices, including Short Delay Free Recall, Long Delay Free Recall, and Long Delay Cued Recall, only one of these is included in the statistical analyses as a measure of delayed recall ability. Specifically, past studies have referred to performance on the Long Delay Free Recall Trial of the CVLT as a reliable indicator of memory impairment, and thus it is included as a predictor in the discriminant function analysis. In addition, it is unnecessary to study the proportion of words recalled from the beginning of the list, the middle of the list, and the end of the list because "primacy," "middle," and "recency" effects directly influence one another. For the purpose of this study, only the "recency" effect is included, as this variable is an indicator of a passive, less efficient learning style, compared to recall of words from the beginning or middle of a word list. Similarly, in terms of clustering style, it is redundant to analyze both the tendency to organize words according to semantic category (Semantic Clustering) and the tendency to recall words in the order they were presented (Serial Clustering). The Semantic Clustering score, reported to be a characteristic of efficient learning, is included in the current analyses.

Other CVLT-II SF variables that are included as predictors in the discriminant function analysis include the Learning Trial 1 score, as a measure of immediate auditory attention or attention span, and the total score from Learning Trials 1 to 4, as a measure of general verbal learning. In terms of recognition ability, the Total Recognition Discriminability score is included rather than including separate scores for the total number of target words recognized (Hits) and the total number of distracters incorrectly identified (False Positives). Finally, to aid in distinguishing between encoding and retrieval deficits, a score contrasting the performance between recognition and free recall ability is included. A list of the variables entered into the discriminant function analysis is found in Table 1. Standard discriminant functions are calculated and predictors which best distinguish between the stroke groups are identified. CVLT-II SF variables with loadings/correlations below $r = .3$ are considered to be poor predictors in terms of their ability to differentiate the three stroke groups. The guideline of $r = .3$ (9% of the variance) has been suggested as a meaningful correlation by Tabachnick and Fidell (2000). Subsequently, the percentage of individual cases correctly classified by this method is reported.

Table 1

CVLT-II SF Variables Included in the Discriminant Function Analysis

Aspect of Memory Functioning	CVLT-II SF Variables Used in Discriminant Function Analysis
Attention span	List-Learning Trial 1 (Trial 1)
General verbal learning	List-Learning Trials 1-4 Total (Trials 1 – 4)
Delayed recall	Long Delay Free Recall (LDFR)
Learning strategy	Semantic Clustering
Serial position	Recency
Recognition memory	Total Recognition Discriminability
Recall/recognition contrast	Total Recognition Discriminability versus Long Delay Free Recall

RESULTS

Descriptive Statistics

Demographic statistics reveal that the stroke sample consists of 75 acute rehabilitation inpatients with a history of stroke. The neuropsychological test battery was administered an average of 20 days post-stroke (*SD* = 11.3). Lesion location determined by radiology reports (CT or MRI scans) reveal that 21 (28.0%) experienced a left cortical stroke, 20 (26.7%) had a right cortical stroke, and 34 (45.3%) were diagnosed with subcortical stroke. Thirty-two of the participants had at least one prior stroke. All but two are right-handed, and both of the left-handed individuals are in the subcortical stroke group. See Table 2 for a summary of patient characteristics.

As to the educational background, a one-way between groups ANOVA reveals that the three stroke groups do not differ significantly in years of education ($M = 10.6$ years, $SD = 3.0$). Reading ability also did not differ among the groups according to scores on the Wide Range Achievement Test – Third Edition (WRAT-3; Wilkinson, 1993) – Reading Subtest. A histogram illustrates the profile of WRAT-3 Reading subtest scores obtained by the left cortical, right cortical, and sub-cortical stroke groups (See Figure 1). Severity of stroke is judged to be similar amongst the three stroke groups based on functional independence level at admission (Functional Independence Measure – Total Score; Hamilton et al., 1987); however, the group's mean scores are significantly different on a screener of general cognitive ability, the Mini Mental Status Exam (Folstein, Folstein & McHugh, 1975) [$F(2, 69) = 13.01$; $p < .01$]. Tukey's post-hoc tests reveal that the left cortical stroke group scored lower than the right cortical and subcortical stroke groups on this measure.

Table 2

Demographic Characteristics and Lesion Locations of the Total Stroke Sample

	N	%
Gender		
Female	47	62.7
Male	28	37.3
Ethnicity		
Caucasian	9	12.0
African American	65	86.7
Hispanic	1	1.3
Handedness		
Right	73	97.3
Left	2	2.7
Lesion Location		
Subcortical	34	45.3
Left Cortical	21	28.0
Right Cortical	20	26.7

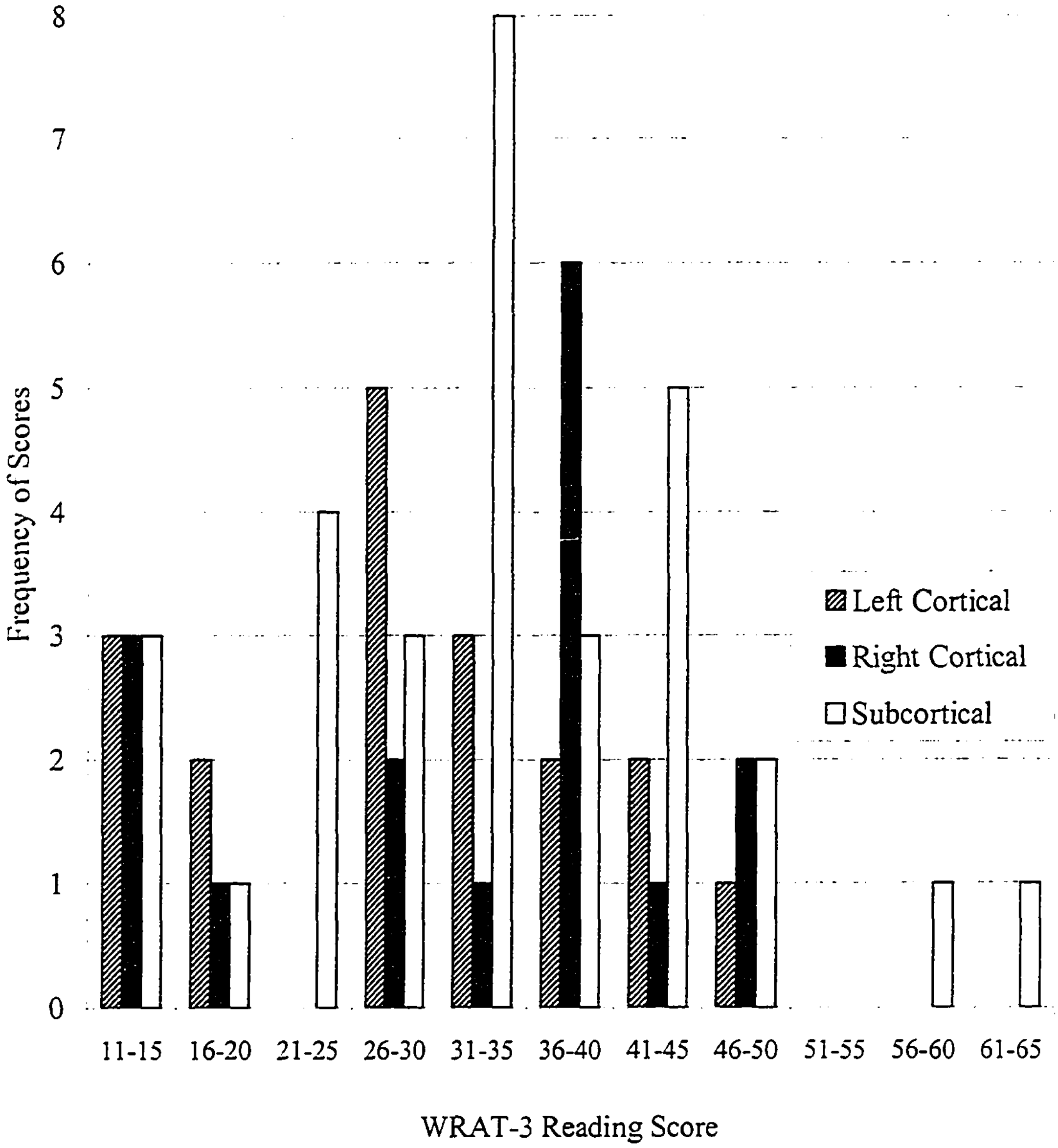

Figure 1. Frequencies of WRAT-3 Reading Scores in Individuals with Left Cortical, Right Cortical and Subcortical Stroke

The mean age of patients in this study is 67.2 years (*SD* = 11.9). A significant difference was noted in the ages of the three stroke groups [$F(2, 72) = 5.79$; $p < .01$], and post-hoc Tukey's tests show that the left cortical stroke group is significantly older than the subcortical stroke group. However, the group with right cortical stroke is not significantly different in age from the other two groups. The left cortical group ranges in age from 45 to 84 years (*M* = 73.6, *SD* = 8.6), the right cortical group ranges in age from 44 to 88 (*M* = 67.5, *SD* = 12.3), and the subcortical group ranges from 46 to 87 years (*M* = 63.1, *SD* = 11.8). Means and standard deviations for years of education, reading level, Functional Independence Measure total scores at admission, Mini Mental Status Examination scores, and age based on site of stroke are shown in Table 3.

Internal Consistency of the CVLT-II SF

Internal Consistency of Learning Trials

Adequacy of the internal consistency of the CVLT-II SF's learning trials is measured using Cronbach's alpha and Spearman-Brown split-half correlations. The estimated internal consistency of the four learning trials is 0.87 based on Cronbach's alpha. The split-half internal consistency , using the Spearman-Brown formula to examine odd versus even numbered learning trials is 0.86. Both these methods suggest a high level of internal consistency in this sample of individuals with stroke.

Internal Consistency of Items from the Recognition Trial

An internal consistency analysis of the items from the recognition trial of the CVLT-II SF using the Kuder-Richardson formula yields a coefficient of 0.75, which is judged to be of an adequate level. Table 4 provides a summary of the internal consistency coefficients obtained.

Table 3

Mean and Standard Deviations of Age, Years of Education, Reading Level, Mini Mental Status Exam Score, and Total Functional Independence Measure Score at Admission for Individuals with Left Cortical, Right Cortical and Subcortical Stroke

	Stroke Group					
	Left Cortical (n = 21)		Right Cortical (n = 20)		Subcortical (n = 34)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Age	73.62_a	8.65	67.50	12.34	63.09_a	11.78
Years of Education	9.71	3.30	9.95	2.76	11.47	2.76
Wide Range Achievement Test – Third Edition - Reading Subtest (Raw Score)	29.33	10.24	32.00	11.58	32.11	11.34
Mini Mental Status Exam (Total Score)	17.15_{bc}	5.03	22.42_b	4.74	23.24_c	3.63
Functional Independence Measure (Total Score at Admission)	58.60	8.85	55.65	12.77	63.17	10.72

Note. Means with the same subscript differ significantly at $p < .01$

Table 4

Internal Consistency for CVLT-II SF Learning Trials and the Items from the Recognition Trial

CVLT-II Variables Examined	Method of Analysis	Internal Consistency Coefficients
Trials 1 to 4	Cronbach's Alpha	0.87
Trials 1+3 versus Trials 2+4	Spearman-Brown Split-Half	0.86
Items from Recognition Trial	Kuder-Richardson	0.75

Construct Validity of the CVLT-II SF

Construct validity of the selected CVLT-II SF indices is examined by correlating scores obtained on CVLT-II SF variables (Trial 1, Trial 1 to 4, and LDFR) and neuropsychological tests selected to represent convergent and divergent measures. A Pearson correlation matrix, along with 99% confidence intervals obtained using Fisher's z' transformations, is found in Table 5. Of note, scores on the RBANS Line Orientation test are not normally distributed, with skew representing a high proportion of subjects obtaining raw scores near zero.

The highest number of digits recalled in the forward direction on the WAIS-III Digit Span subtest correlated highly with the CVLT-II SF Trial 1 ($r = .41, p = .000$), total score from Trials 1 to 4 ($r = .49, p .000$) and long delay free recall (LDFR) ($r = .39, p = .001$). Immediate and delayed recall of narrative information (RBANS Story Memory I and II) also correlates highly with the CVLT-II SF scores. In particular, RBANS Story I correlations with the CVLT-II SF include $r = .67$ ($p = .000$) for Trial 1, $r = .66$ ($p = .000$) for Trials 1 to 4, and $r = .56$ ($p = .000$) for LDFR. RBANS Story II correlations with the CVLT-II SF include $r = .67$ ($p = .000$) for Trial 1, $r = .77$ ($p = .000$) for Trials 1 to 4, and $r = .62$ ($p = .000$) for LDFR.

Correlations between the CVLT-II SF variables and the discriminant measures (i.e., RBANS Line Orientation, WASI Similarities, and Oral Trail Making Test Part B) reveal that the Oral Trail Making Test Part B and the RBANS Line Orientation subtest do not correlate at a significance level of .01 with the CVLT-II SF. However, the WASI Similarities subtest correlates strongly with the CVLT-II SF measures of attention ($r = .43, p = .001$), immediate recall ($r = .57, p = .000$) and delayed recall ($r = .37, p = .006$).

Table 5

Pearson Correlations of Raw Scores from Selected CVLT-II SF Variables and Neuropsychological Measures (with 99% Confidence Intervals)

		CVLT-II SF Variables		
Neuropsychological Measure		Trial 1	Trials 1-4	LDFR
WAIS-III Digit Span (Highest Number of Digits Recalled Forward)	*r*	.41 *	.49 *	.39 *
	CI	(.13 to .63)	(.23 to .69)	(.11 to .61)
RBANS Story Memory I	*r*	.67 *	.66 *	.56 *
	CI	(.47 to .81)	(.45 to .80)	(.32 to .73)
RBANS Story Memory II	*r*	.67 *	.77 *	.62 *
	CI	(.47 to .81)	(.61 to .87)	(.40 to .77)
RBANS Line Orientation	*r*	.03	.29	.10
	CI	(-.27 to .32)	(-.01 to .54)	(-.20 to .38)
WASI Similarities	*r*	.43 *	.57 *	.37 *
	CI	(.15 to .64)	(.33 to .74)	(.08 to .60)
Oral Trail Making Test Part B	*r*	-.25	-.25	-.16
	CI	(-.51 to .05)	(-.51 to .05)	(-.43 to .14)

Note. *r* = Pearson correlation coefficient
CI = 99% Confidence Interval based on Fisher's r to z' transformations
* $p < .01$

Using the CVLT-II SF to Distinguish Between Subgroups of Stroke

Data were initially examined for missing values, normal distribution of variables, univariate and multivariate outliers, and multicollinearity. There were no missing values or outliers, the variables were normally distributed, and there were no issues of multicollinearity. A correlation matrix displaying intercorrelations for the selected CVLT-II SF measures is presented in Table 6. No correlations were above $r = .80$, and therefore all selected variables were included in DFA analyses. Note that Tabachnick and Fidell (2000) suggest that variables with correlations .90 and higher create statistical problems as variables contain redundant information. Collinearity diagnostics revealed no conditioning index larger than 30 (the last root approached 20). Criteria for multicollinearity suggested by Belsely, Kuh, and Welsch (1980) are a conditioning index > 30 for a given dimension coupled with two variance proportions > .50.

Seventy-five cases were processed. Initial analysis of the results reveals that nearly half of the total sample have difficulty with delayed recall of verbal information, with long-delay free recall (LDFR) z scores equal or less than two standard deviations below the normative group in 34 of 75 (45.3%) of individuals.

Tests of Equality of Group Means

Prior to performing the standard discriminant function analysis (DFA) using the CVLT-II SF measures as predictors of membership in the three stroke groups, an ANOVA along with Tukey's post-hoc analyses, revealed that the stroke groups perform significantly different on several CVLT-II SF measures. The left cortical stroke group scored lower than the right cortical and subcortical groups on measures of attention, immediate recall, delayed recall, and recognition, with their performance judged to be

Table 6

Intercorrelations for Raw Scores from Selected CVLT-II SF Variables

CVLT-II SF Variables	1	2	3	4	5	6	7
1. Trial 1	--						
2. Trials 1-4	.78 *	--					
3. LDFR	.57 *	.72 *	--				
4. Semantic clustering	.13	.15	-.03	--			
5. Recency	-.27	-.37 *	-.32 *	-.17	--		
6. Recognition Discriminability	.51 *	.62	.71 *	.04	-.28	--	
7.Recall/Recognition Contrast (z-score)	.08	-.01	-.21	.14	-.01	.35 *	--

Note. * $p < .01$

within the impaired range compared to the normative data (See Figure 2).

Analysis of performance on the CVLT-II SF variables of interest, reveals that on the first learning trial (Trial 1) individuals in the three stroke groups performed differently [F (2,72) = 29.96; p = .000]. Tukey's post-hoc analysis reveals that subjects with left cortical stroke have lower scores (M = 1.76, SD = 1.51) than subjects with right cortical (M = 4.00, SD = 0.79) and subcortical strokes (M = 4.18, SD = 1.14). Similarly, subjects with left cortical stroke (M = 12.67, SD = 5.68) perform significantly poorer than subjects with right cortical (M = 20.15, SD = 3.53) and subcortical stroke (M = 20.91, SD = 4.21) on the total score from learning Trials 1 to 4, a measure of immediate recall [F (2,72) = 23.72; p = .000]. Ability to recall the words after a long delay, as measured by the LDFR variable, is also significantly poorer in the left cortical group (M = 0.86, SD = 1.53) compared to the right cortical (M = 3.65, SD = 2.01) and subcortical groups (M = 2.85, SD = 2.40) [F (2,72) = 10.04; p = .000]. In addition, the left cortical group appears to recall more words from the recency section of the list than the subcortical group [F (2,72) = 5.36; p = .007]. In terms of ability to identify target words on a recognition trial, the left cortical stroke group attained the lowest scores, and perform significantly poorer than that subcortical stroke group on this measure [F (2,72) = 4.50; p = .014]. The right cortical group performed similar to the other stroke groups on the latter two measures.

No group differences are revealed on measures of semantic clustering or retrieval deficit based on a recall/recognition contrast score. The mean scores for the three groups were all within the average range on these measures. Performance, including means and standard deviations, by the three stroke groups on the CVLT-II SF variables of interest are shown in Table 7.

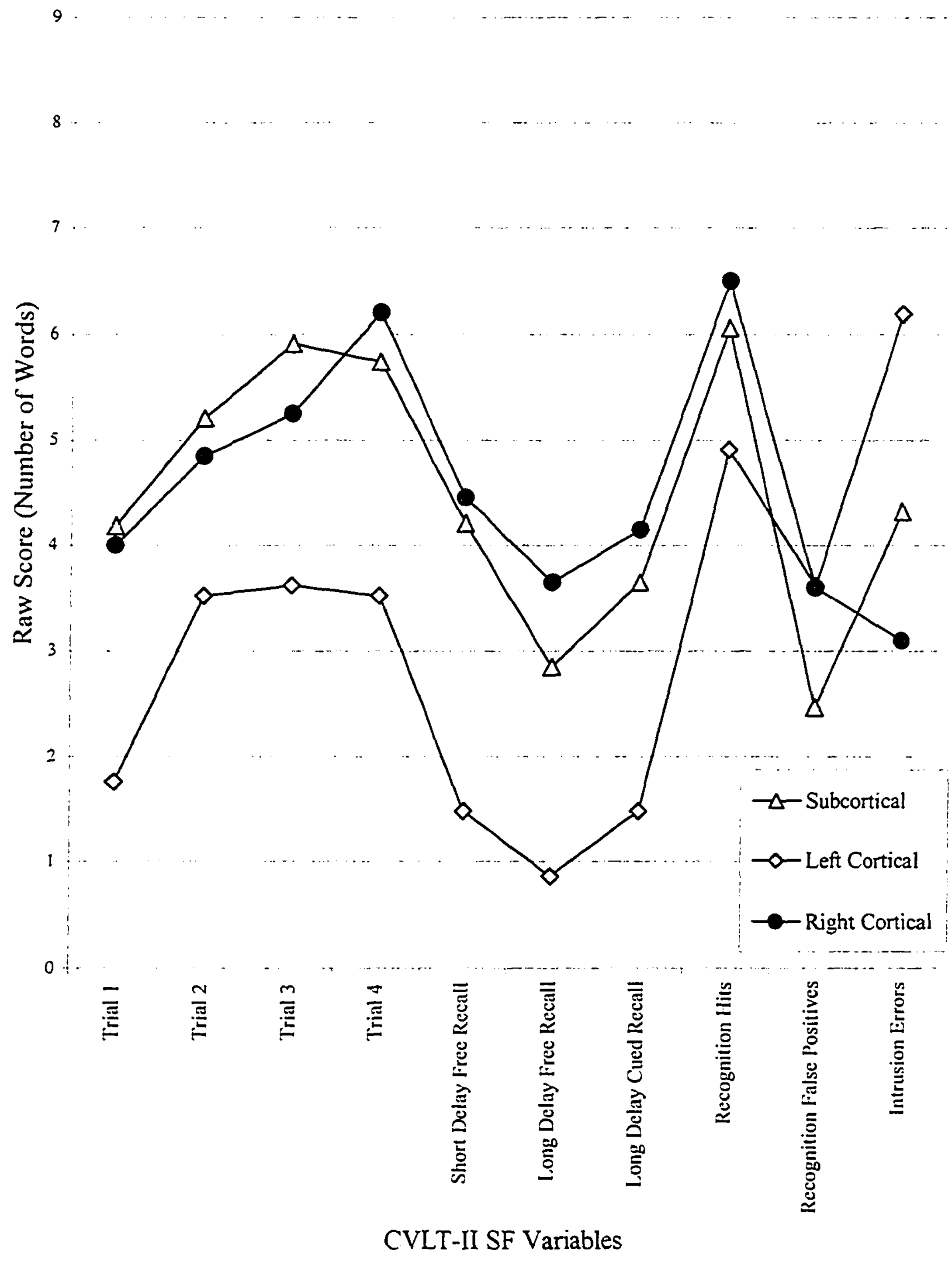

Figure 2. Performance by Three Stroke Groups on CVLT-II SF Learning Trials, Recall Trials and Recognition Task.

Table 7

Test of Equality of Group Means (with Standard Deviations) of Predictor CVLT-II SF Variables as a Function of Stroke Lesion Location

	Stroke Group								
	Left Cortical		Right Cortical		Subcortical				
CVLT-II SF Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	Tukey Post-hoc*
Trial 1	1.76	1.51	4.00	0.79	4.18	1.14	29.96	.000	L<R=S
Trials 1-4	12.67	5.68	20.15	3.53	20.91	4.21	23.72	.000	L<R=S
LDFR	0.85	1.53	3.65	2.01	2.85	2.40	10.04	.000	L<R=S
Semantic clustering	-0.31	0.54	-0.02	0.40	-0.07	0.47	2.79	.110	
Recency	46.81	22.77	33.05	12.45	34.59	10.29	5.36	.007	L>S
Recognition Discriminability	1.14	0.88	1.69	0.67	1.84	0.94	4.50	.014	L<S
Recall/ Recognition Contrast (z-score)	0.45	-.67	0.13	0.72	0.41	0.67	1.46	.240	

Note. *L = patients with left cortical stroke; *R* = subjects with right cortical strokes; S = subjects with subcortical strokes.

Discriminant Function Analysis of the CVLT-II SF

DFA predictors include seven CVLT-II SF variables of interest: attention span, general verbal learning, delayed recall, recency effect, semantic clustering, recognition discriminability, and recall/recognition contrast. The DFA resulted in two discriminant functions, with the first achieving statistical significance. This discriminant function accounts for 89% of the variance between the groups, and has a Wilks' Lambda of 0.40 and a chi-square of 63.12 ($p < .01$). This suggests that the discriminant function is useful for differentiating the groups (See Figure 3 for profiles of discriminant functions obtained by individuals in each of the three stroke groups). Group centroids included -1.70 for the left cortical stroke group, 0.65 for the right cortical stroke group, and 0.67 for the subcortical stroke group. The total score from Learning Trial 1 is identified as the best predictor ($r = .84$) followed by the total score from CVLT-II SF Trials 1-4 ($r = .75$). The Recall/Recognition contrast measure and the Semantic Clustering variable do not contribute to the discriminant function ($r < .3$). See Table 8 for standardized canonical discriminant function coefficients and correlations between CVLT-II SF variables and discriminant functions.

A jackknife classification procedure is important to determine if cases are adequately classified into the three stroke groups. Because diagnostic accuracy of a test is at least partially dependent on the base rate of a diagnosis in a clinical population, and considering that subcortical strokes occur more frequently than cortical strokes in the general population (Longstreth et al., 2002). The classification procedure was conducted computing probabilities based on the original group sizes. Results suggest that the overall percentage of cases correctly classified is 72.0 %.

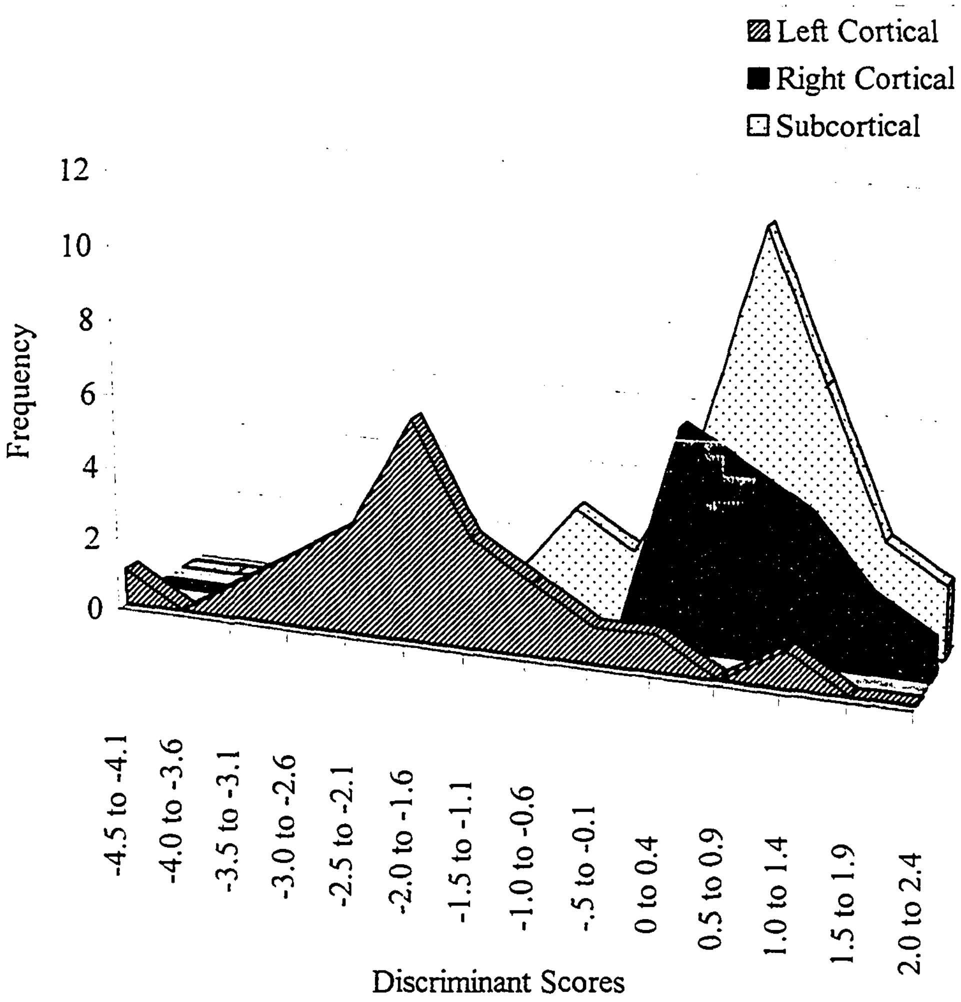

Figure 3. Using Selected CVLT-II SF Variables to Differentiate Between Stroke Groups: Observed Frequency Distribution of Discriminant Scores

Table 8

Correlation of Predictor CVLT-II SF Variables with the Discriminant Function (Function Structure Matrix) and Standardized Discriminant Function Coefficients

CVLT-II SF Variable	Correlation with Discriminant Function	Standardized Discriminant Function Coefficients
Trial 1	.840	.765
Trials 1-4	.746	.298
LDFR	.463	-.142
Recency	-.353	-.275
Recognition Discriminability	-.319	.030
Semantic Clustering	.228	.277
Recall/ Recognition Contrast	-.090	-.347

Note. CVLT-II SF variables are ordered by absolute size of correlation with the significant function, Function 1.

Eighteen out of 21 (85.5 %) individuals with left cortical stroke are correctly classified, 8/20 (40.0 %) of individuals with right cortical strokes are correctly classified, and 28/34 (82.4 %) of individuals with subcortical strokes are correctly identified (see Table 9).

The initial descriptive data analysis revealed a significant difference between the ages of the left cortical and subcortical stroke groups, with the left cortical stroke group being older. To determine if age has a significant role in differentiating between the three stroke groups, the DFA is repeated including age as well as the seven CVLT-II SF variables of interest. This DFA results in two discriminant functions, with the first being statistically significant. The first function accounts for 87% of the variance between the groups (Wilk's Lambda = 0.39, Chi-square = 64.37, $p < .01$). The stroke groups are differentiated using discriminant function analysis. The measure of attention span (total score from Learning Trial 1) is again identified as the best predictor ($r = .84$), and the measure of general verbal learning (total score from CVLT-II SF Trials 1-4) is again the second best predictor ($r = .75$). Age has the least absolute size of correlation with the discriminant function, and the addition of age as a predictor does not improve the classification rate.

Table 9

Classification Analysis for Stroke Subgroups

		Predicted Group Membership					
		Left Cortical		Right Cortical		Subcortical	
Actual Group Membership	n	n	%	n	%	n	%
Left Cortical	21	18	85.7	0	0.0	3	14.3
Right Cortical	20	2	10.0	8	40.0	10	50.0
Subcortical	34	2	5.9	4	11.8	28	82.4

Note. 72.0 % of the original grouped cases are correctly classified.

DISCUSSION

The main objective of this investigation was to determine whether patterns of performance on selected variables from the CVLT-II SF could differentiate between three groups of stroke patients. This abbreviated measure is relatively new, with no known published research on its usefulness. To claim utility for differentiating between individuals with various memory profiles, the test must first demonstrate adequate psychometric properties. It was hypothesized that the CVLT-II SF would have adequate internal consistency and validity, and that it would be useful in discriminating between memory abilities of three groups of stroke patients: (1) left cortical, (2) right cortical and (3) subcortical ischemic stroke.

Internal Consistency of the CVLT-II SF

In the stroke sample studied, the internal consistency of the four learning trial scores exceed 0.80 using both coefficient alpha and split-half methods, and are thus thought to be highly inter-correlated, and of good clinical significance. Although the goal of the current study was not to directly make comparisons between the utility of the CVLT-II short and the standard form, it is worthwhile to comment on the internal consistency of the CVLT-II standard form. According to the CVLT-II manual (Delis et al., 2000), using a split-half method, the internal consistency coefficient of the learning trials from the standard form is $r = .94$ in the normative population ($N = 1087$). The test manual suggests that the correlation coefficients on the learning trials of the CVLT-II are above .90, even when considering different age groups and gender. The manual also indicates that the same split-half method employed with a heterogeneous clinical sample (i.e., chronic pain, Parkinson's disease, frontal surgery, depression, Huntington's disease and stroke) of 124 patients, also results in a very high internal consistency (r = .96). Direct comparison cannot be made to the results found using the current stroke sample, though findings appear to suggest that the internal consistency using the standard form may be more robust than when using the short form. For this study, a relatively lower internal consistency coefficient was anticipated due to the reduced length of the word list, as well as the heterogeneous clinical population used. Nevertheless, it was found that the four learning trials of the CVLT-II SF are sufficient to give a consistent estimate of recall ability in an inpatient stroke sample.

Next, the internal consistency of the items on the recognition trial of the CVLT-II SF was examined in the same stroke sample. Using the Kuder-Richardson formula the interrelatedness of the items was interpreted to be adequate (KR-20 = 0.75). A correlation coefficient of .75 is not remarkably high, and may possibly be limited in part by the nature of the data used (dichotomous data), the conservative measure employed to analyze it, as well as the relatively short length of this trial. However, this level of correlation still provides convincing evidence regarding the consistency of the items included in the recognition trial of the CVLT-II SF, at least in terms of the sample studied. Test developers did not examine the internal consistency of the recognition items from the standard CVLT-II, so it is not possible to make comparisons with the current findings.

Overall, the list-learning and recognition items on the CVLT-II SF have a good level of internal consistency. This suggests that use of the abbreviated CVLT-II is supported by its degree of homogeneity within the learning and recognition trials, although additional psychometric measurements are crucial. The degree of homogeneity does not directly testify as to the quality of the test. In fact, many tests with low internal consistency, resulting from a wide array of cognitive domains assessed, are highly valued by neuropsychologists. Knowing that different variables of a test assess the same concept supplies little information in isolation, but has relevance to further analyses of validity; consequently, it is crucial to consider data external to the test itself.

Construct Validity of the CVLT-II SF

The CVLT-II SF, similar to other list-learning tasks, is designed to measure memory for verbal information. However, assuming that this is true does not necessarily make it so. Thus, it was necessary to explore the CVLT-II SF's validity as shown by its relationship to standardized neuropsychological measures. It was hypothesized that indices of the CVLT-II SF would be highly correlated with measures of attention span and memory for narrative information, but not with other domains of neuropsychological functioning including visuospatial perception, verbal concept formation, and cognitive flexibility.

In terms of the convergent validity, results suggested that the CVLT-II SF correlated highly with measures of attention span (WAIS-III Digit Span) and memory for verbal information (RBANS Story Memory). Thus, the CVLT-II SF is judged to possess high convergent validity. This is similar to findings with the standard CVLT that revealed moderate to high correlations with measures of immediate auditory attention (Delis et al., 1988) and of memory for verbal information (Crosson & Wiens, 1994; Delis et al., 1988; Lacritz, Cullum, Weiner, & Rosenberg, 2001; McDowell et al., 2004; Woodward et al., 1996).

The WAIS-III Digit Span score correlated highly with the first learning trial of the CVLT-II SF, but also with the immediate and long-delay recall trials. Similarly, the RBANS Story Memory correlated highly with a variable of the CVLT-II SF reported to assess immediate auditory attention, as well as the indices measuring immediate and delayed recall. It is believed that both attention span and memory are necessary cognitive functions required for successful performance on the CVLT-II SF, and that attention and memory are interdependent. This is clinically relevant, as neuropsychologists should be cautious before interpreting a patient's general verbal learning based on the total score from the CVLT-II SF Trials 1 to 4. In fact, it may be very possible that an individual could achieve a high score on Trials 1 through 4, even if their memory is quite poor, as long as their attention span is within normal limits. This supports previous research stating that earlier trials on the CVLT place larger demands on auditory attention span than supraspan learning (Delis et al., 1991; Massman et al., 1990). Thus, it may be necessary to verify memory performance levels using later trials of the test including the long-delay cued recall and recognition trials, as well as supplementary measures of attention and memory.

When examining correlations between the CVLT-II SF variables and neuropsychological measures reported to assess domains unique from attention and memory, the discriminant validity of the CVLT-II SF is judged to be somewhat questionable. Although divergent validity was indicated by lack of high correlations with measures of cognitive set shifting (Oral Trail Making Test - Part B) and visuospatial perception (RBANS Line Orientation), the CVLT-II SF did correlate positively with one of the tests chosen as a divergent measure, namely, the WASI Similarities subtest.

Most neuropsychological tests require that test-takers possess a minimum level of language comprehension skills to understand the test instructions, as well as a minimum level of arousal in order to attend to the demands of the test. Apart from these basic functions, the strong correlation between the WASI Similarities subtest and the CVLT-II SF almost certainly suggests that these measures have even more in common. The most obvious notion is that both of these tasks assess aspects of verbal ability. The CVLT-II SF is a measure of memory for verbal information, and thus it makes sense that it would correlate more strongly with tests of verbal ability than tests of nonverbal ability. In fact, when reviewing previous research on the original CVLT, the relationship between language skills and verbal memory skills is documented. For example, the Wechsler Adult Intelligence Scale – Revised (WAIS-R) Vocabulary subtest, a test requiring the examinee to accurately provide definitions of words, has been found to predict up to 13% of the variance of the original CVLT (Keenan et al., 1996). Likewise, a significant correlation between the CVLT-II and the WASI Vocabulary test has been reported (Delis et al., 2000). Studies examining the role of verbal functioning during testing with the CVLT-II SF would be useful to determine if findings would be consistent using this test.

However, basic verbal output is unlikely to account for the full extent of the correlations obtained, as even the Oral Trail Making Test requires generation of words. As previously mentioned, the WASI Similarities subtest is reported to be a measure of verbal abstraction. It appears that organization of verbal material may also be common to both the WASI Similarities subtest and the CVLT-II SF. Specifically, the CVLT-II SF consists of words that can be actively organized words into semantic categories.

Organization skills are also necessary when discriminating between correct test words and errors.

Correlations with the WASI Similarities subtests implies that the CVLT-II SF may assess processes from cognitive domains beyond those that it was designed to assess. This finding has previously been reported in studies of the original CVLT (Tremont, Halpert, Javorsky, & Stern, 2000) and the "Dementia Version" of the CVLT (Woodward et al., 1999). For example, in some samples assessed, these versions of the CVLT are correlated with measures of memory for visual information (e.g., DiPino, Kabat, & Kane, 2000; Woodward et al., 1995) and tests of working memory, word generation, cognitive set-shifting, and generating and switching between problem-solving strategies (e.g., Tremont et al., 2000; Vanderploeg, Schinka, & Retzlaff, 1994). Although findings of impairment in multiple domains may also be the result of diffuse damage, and so similar findings should be sought using healthy control subjects. Thus far, an analysis of performance by the normative sample suggests that the standard form of the CVLT and CVLT-II have modest correlations with education level and psychometric intelligence (e.g., Delis et al., 2000; Rapport et al., 1997). Interestingly, using multiple regression analyses, nearly half of the variance in the CVLT indices is accounted for by the WAIS-R Verbal Comprehension Index and the Freedom from Distractibility Index (Rapport et al., 1997). This also supports findings from factor analysis studies on the original CVLT that suggest that the CVLT consists of factors above and beyond a general verbal learning factor (e.g., Delis, Freeland et al., 1988; Gardner & Vrbanic, 1998; Libon, et al.,1996; Millis, 1995; Schear & Craft, 1989; Vanderploeg et al., 1994; Wiegner & Donders, 1999).

In sum, it is important to consider what the CVLT-II SF is really measuring. Strong correlations with tests assessing attention and memory for verbal information suggest that the CVLT-II SF appears useful as a screener of memory ability. However, additional correlations with a measure of verbal abstraction or concept formation suggest that CVLT-II SF scores may not be specific to these domains. Although other tests of memory functioning are judged to be more pure measures of this domain, there are benefits to being able to quickly assess for multiple aspects of cognition, as long as what is being assessed is accurately interpreted. For example, in the rehabilitation setting, one must often provide a quick evaluation in order to suggest compensatory strategies that will make treatments more effective. In fact, there is a trend towards adopting briefer evaluations. Nevertheless, it is warned that screening measures like the CVLT-II SF should not be used as substitutes for more comprehensive evaluations, but rather to guide the neuropsychologist in structuring a more complete evaluation.

Using the CVLT-II SF to Distinguish Between Subgroups of Stroke

The main purpose of the current study was to use DFA to determine if selected CVLT-II SF variables could predict membership in three stroke groups. This is a valuable study because the CVLT was developed for the purpose of identifying and categorizing different memory disorders, and has proven useful in various neurological populations (Delis et al., 1997), although it is not clear if the abbreviated form can capture differences in memory profiles amongst different patient groups. For the current study, it was predicted that the CVLT-II SF could be of similar worth in differentiating between stroke groups based on current knowledge about these groups from neuropsychological investigations.

The three ischemic stroke groups (i.e., left cortical, right cortical, and subcortical) were all thought to be at risk for at least mild changes in memory performance. The right cortical stroke group was expected to have minimal deficits in memory for verbal information, the left cortical stroke group was expected to have severe encoding deficits, and the subcortical stroke group was expected to have memory deficits characterized by difficulty retrieving information.

Consistent with this study's predictions, performance on the CVLT-II SF was useful in differentiating the stroke groups. Findings from an ANOVA and Tukey's post-hoc tests revealed that the left cortical group performed significantly poorer than the right cortical and subcortical groups on most CVLT-II SF indices, whereas the right cortical and subcortical groups were not clearly distinguished from one another based on the predictors used.

Of the seven CVLT-II SF variables entered into the DFA, the best predictors of group membership were the scores from Trial 1 and Trials 1 to 4. It was predicted that the total score from the learning trials would be a strong predictor of group membership, as it represents overall immediate recall ability. This prediction was supported. In past studies using the CVLT, the total score from the learning trials has been interpreted to be a measure of general verbal learning ability and has been highly correlated to other neuropsychological measures (e.g., Millis, 1995), and has demonstrated good sensitivity to brain injury (Garder & Vrbancic, 1998).

Measures of attention were expected to correlate with measures of general verbal learning, as it is assumed that attentional capacity is necessary, albeit not sufficient, for learning. Nevertheless, the finding that the Trial 1 score was the strongest predictor of group membership is not consistent with the original hypotheses. The literature suggests that individuals with stroke display intact basic attention, although impairments are seen as attentional tasks become more demanding (Hochstenbach et al., 1998; Hom & Reitan, 1990; Wade et al., 1986). Likewise, patients with memory impairment due to cortical dysfunction and temporal lobe atrophy in many other neurological conditions (e.g., early stages of Alzheimer's disease and temporal lobe epilepsy), also tend to have generally intact basic attention (e.g., span of digits or spatial information) despite significantly impaired ability to learn and remember (e.g., Baños et la., 2004; Jokinen et al., 2004). In other words, basic attention may be considered to be a less vulnerable domain of cognition functioning compared to memory.

However, in the current study, the left cortical group had weaker recall on the first learning trial compared to the other stroke groups. This may be due to the severity or location of the infarcts. For example, because individuals included in this study did not have strokes restricted to the medial temporal lobe infarcts, their cognitive profiles may include diffuse impairment. For example, individuals with infarcts involving the dorsolateral prefrontal cortex, may have disruptions to the so-called phonological loop, which is conceptualized by Baddeley (2003) to be important for auditory attention processing and working memory (i.e., storage, maintenance, and rehearsal of information) prior to the consolidation of information into long-term storage. It would be important to replicate this study separating groups with temporal and frontal lobe infarcts to confirm this speculation.

The semantic clustering and recall/recognition contrast scores were not useful in distinguishing between the three stroke groups as was hypothesized. Similar scores, generally within normal limits, on these measures across the three groups may suggest that the groups have similar ability to retrieve information. Although the reasons for their similar test scores is unclear. It is possible that the CVLT-II SF may only allow for minimal opportunities to use semantic clustering, considering that there are only a few words on the list from each of the semantic clusters (and only a total of nine words on the entire list). Similarly, the recognition trial has an equally small number of target words to recognize. Thus, due to the limited range of performance assessed by these variables, separation of the groups is potentially minimized. The current study does not clearly illustrate if the CVLT-II SF measures how a learning task is tackled (e.g., use of different strategies) in an inpatient stroke rehabilitation sample. Further investigation of the efficacy of these CVLT-II SF measures is needed. One method would be to directly compare performance on the CVLT-II SF with the CVLT-II Standard Form to see if a greater range of scores is obtained using the longer test form.

Although the CVLT-II SF had some utility in separating the individuals with left cortical stroke from the other groups, its ability to differentiate the three groups was not without limitations. Rather than revealing profiles of learning and memory in this stroke sample, the CVLT-II SF may be restricted to identifying patients with severely impaired memory functioning from those with relatively intact performance.

Overall, as hypothesized, individuals with left cortical lesions had the most severe memory impairment when compared to the other two stroke groups. In particular, when compared to the right cortical and subcortical groups, the left cortical stroke group displayed poorer performance on measures of attention, overall learning, and delayed recall. Compared to the subcortical group, the left hemisphere group recalled more words from the recency section of the list and had lower recognition discriminability scores. In support of this test, a jackknife classification procedure correctly classified the majority of individuals with left cortical strokes (85.7%). This group was expected to show a pattern characterized by encoding deficits, but this pattern of performance cannot be confirmed based on the current findings (e.g., there was not significant difference between mean scores on long-delay free recall and recognition discriminability based on the contrast score).

The finding of impaired memory for verbal information in patients with left hemisphere deficit is frequently cited in the literature. For example, Hildebrandt et al., (1998) documented similar findings in their study of stroke patients on a German version of the original CVLT. Analogous results have been found with other neurological populations including patients with left versus right temporal lobe epilepsy (Baños et al., 2004). Perhaps most striking is evidence of laterality in memory for verbal information in epilepsy patients who have undergone left hippocampal resection, as they clearly display flat learning curves, increased rate of recall from the recency section of the list, and a dependence on serial clustering, when compared to the patients who have undergone right hippocampal resection (Hermann et al., 1996).

The literature suggests that individuals with right cortical lesions generally display average performance on tests of memory for verbal information (e.g., Kertesz & Dobrowski, 1981), and they are even sometimes included in studies as the control group (e.g., Hildebrandt, Brand, & Sachsenheimer, 1998). It is important to mention that right cortical stroke groups do not perform within the normal range on all indices of verbal learning tests, as they tend to show difficulty with organization and semantic properties of list-learning tests (e.g., Villardita et al., 1988). In the current study, the right cortical group did not display a pattern of normal learning and memory. In fact, their mean performance was not significantly different from the other groups on several of the measures, including recognition discriminability. This group was poorly classified using the DFA jackknife classification method, with many cases misclassified as subcortical stroke patients. In general, the CVLT-II SF may be beneficial in distinguishing between patterns of performance in stroke patients with left versus right stroke (or left vs. subcortical stroke), but it does not appear useful in distinguishing between the patterns of performance in individuals with right versus subcortical stroke.

The subcortical stroke group performed relatively better on the CVLT-II SF than the left cortical stroke group, and was well-classified based on the jackknife classification method. Nevertheless, this group did not appear to be distinguished based on the expected profile of retrieval deficits. Past research examining memory profiles in patients with subcortical dementia (e.g., Parkinson's and Huntington's disease) has suggested that these patients can be well differentiated from individuals with cortical dysfunction, such as those with Alzheimer's disease (e.g., Albert, 1978; Brown & Marsden, 1988). Specifically, subcortical dementia has been characterized by poor recall of words on the CVLT but relatively intact learning and retention, whereas patients with cortical dementia appear to show deficits in all these variables (e.g., Delis et al., 1991; Delis et al., 2000; Lundervold, Reinvang, & Lundervold, 1994). The current study did not find that the CVLT-II SF was particularly useful at differentiating between right cortical and subcortical stroke based on semantic clustering or recognition discriminability. It is possible that choosing different variables from the CVLT-II SF would lead to better differentiation of the groups. In a study by Kramer et al., (1989), groups of patients with Alzheimer's, Huntington's and Parkinson's disease were successfully differentiated using a score reflecting the proportion of intrusion errors to the total responses. In addition to examining intrusion errors, better diagnostic accuracy may be obtained using composites of CVLT-II SF variables such as measures of learning slope or retention.

Another interesting finding of this study was that in a parallel calculation of a discriminant analysis that included age as an additional predictor, age did not improve the classification of individuals with stroke. The current findings suggest that age may not contribute a significant proportion of the variance to the model that differentiated the three stroke groups; however, this finding must be scrutinized. It is reported in the literature that with increasing age memory performance declines (e.g., Luszcz & Bryan, 1999). In analyses of the CVLT-II Standard Form, Delis et al. (2000) report that the correlation between age and recall performance is significant, with decreased recall related to increasing age. Thus, reasons for the minimal age effect may be associated to the proposed idea that the abbreviated version of the CVLT-II does not adequately assess the limits of memory, especially in individuals with relatively good memory ability. This warrants further investigation.

Clinical implications

Memory, once considered a unitary construct, has evolved into a subset of various components, perhaps best described as a system. List-learning tests are reported to measure distinct components of memory and detect individual differences in patterns of memory performance. This attribute of list-learning tests is especially valuable in diagnosis and providing individuals with suitable treatment recommendations, such as compensatory mechanisms to deal with specific deficits in memory functioning. Although the CVLT-II SF has a number of appealing qualities, such as the ability to assess individuals with severe levels of impairment in memory, as well as the opportunity to collect a vast number of index scores within a short administration time, it is important to take caution when using an abbreviated test.

A nine-word list may not be sufficient to test the limits of memory in most individuals. Ceiling effects have been reported when using similar list-learning tests, including measures with lists that are significantly longer in length. For example, the RAVLT, a 15-word list, is reported to have severe ceiling effects on the fourth and fifth learning trials (Graf & Uttl, 1995). Ceiling effects are objectionable for a number of reasons, for example, they create a compression of score distribution due to an inability to adequately assess individuals with abilities at the upper ends of the spectrum. In other words, a shortened test may underestimate the abilities of some individuals due to the reduction in range of measurable performance. Overall, despite theoretical similarities between the CVLT-II SF and the longer standard version, the short form may not be challenging enough to elicit some of the patterns expected to the same extent as the standard form. Use of the CVLT-II SF should be restricted to populations it was designed to assess, including individuals with moderate or severe cognitive impairment.

The current investigation reveals that the CVLT-II SF is not as useful as expected in identifying distinct styles of verbal learning and memory patterns, at least within this stroke rehabilitation sample. This finding comes with an important practical implication. Neuropsychologists using this measure are cautioned when they attempt to interpret the clinical meaning of scores. For example, in a rehabilitation setting, where therapists frequently consult neuropsychologists to learn how to best teach patients how to gain skills in self-care and adaptive behaviours (e.g., if they should use repetition/cueing), little confidence can be placed in CVLT-II SF test scores to convey such recommendations.

Is it even worthwhile to administer the CVLT-II SF? When differentiating between stroke groups, most of the variance was accounted for by the first four learning trials. These trials may be sufficient to determine whether or not a patient has an impairment in learning verbal information. Although merely administering only Trial 1 or Trial 1 to 4 is definitely not recommended, it is emphasized that clinicians may wish to adhere to using the standard version of the CVLT-II, until more research is done using the CVLT-II SF in various patient populations.

Limitations and Future Directions

Studies on the utility of the CVLT-II SF are in their early stages. The CVLT-II SF appears useful as a brief screener to distinguish patients based on the severity of their memory impairment; however, this tool's ability to distinguish between patterns of memory (i.e., encoding vs. retrieval deficits) was not clearly illustrated in the stroke sample studied. Although the current sample size was adequate to yield reliable DF coefficients, this sample size was not large enough to complete an independent-sample cross-validation. Therefore, further studies are necessary to better understand the ability of the current results to generalize to other populations. Perhaps with a larger sample size other statistical methods could be used, such as determining if subtypes of verbal learning and memory could be obtained using factor analytic studies. Multinomial logistic regression could also provide an alternative to discriminant function analysis, allowing for direct testing and interpretation of the contribution of individual variables in the model.

Neuropsychological examination was performed approximately 3 weeks post-stroke. However, caution must be taken when interpreting scores at this early stage post-stroke because many of the deficits identified may improve. A repetition of this study at 6 months or 1 year post-stroke would be of interest.

Use of referred patients may bias the sample by restricting the range of potential scores, because patients considered for rehabilitation require a minimum level of impairment to qualify for rehabilitation, yet often do not have severe impairments as seen in patients admitted to the intensive care unit. Nevertheless, the sample utilized in this study accurately represents the type of patients who are considered for rehabilitation post-stroke.

In terms of replication with other stroke samples, it will be useful to determine if the CVLT-II SF can discriminate between patients with strokes in left temporal regions from those with strokes in left frontal regions, and similarly with right temporal and frontal lobe stroke patients. This is important because individuals with frontal lobe strokes may demonstrate a more active learning strategy than individuals with temporal lobe strokes, which could be illustrated by higher scores on the recognition trial and greater benefit from semantic cues when compared to individuals with temporal strokes (e.g., Hildebrandt et al., 1998; Jetter et al., 1996; Winocur, 1992). Likewise, it will be important to determine if the CVLT-II SF is useful for diagnosis and differentiation of cortical versus subcortical dementia (e.g., Alzheimer's disease vs. subcortical vascular dementia), as these conditions, which are not readily distinguished using neuroimaging techniques, have been well-differentiated using the standard form of the CVLT.

Future studies on the utility of the CVLT-II SF should include a healthy control sample in addition to a neurologically impaired sample, as data could be used to derive sensitivity rates (i.e., cut-off scores that differentiate healthy controls from subjects with impairments in memory). Research on the reliability and validity of the CVLT-II SF in healthy control subjects, including direct comparisons to the standard version, may show that abbreviating this affects the psychometric qualities when using a control sample. It is anticipated that if problems are noted with differentiating individuals with a cognitively impaired sample, such as the current inpatient stroke rehabilitation sample, the ability of the CVLT-II SF to differentiate between high-functioning individuals will be much worse. This is because of potential ceiling effects, as most cognitively intact individuals can recall seven, plus or minus two items, on the basis of attention span alone. In fact, several repetitions of the list may not be necessary for many individuals to recall nine items.

Final Remarks

In conclusion, the current study reveals that the CVLT-II SF has a number of strengths and weaknesses. It appears to demonstrate good internal consistency and relatively good ability to discriminate individuals with left hemisphere stroke from those with right cortical and subcortical stroke. This tool is thought to be useful if a clinician requires a quick screening measure to determine whether or not a patient has a significant deficit in memory for verbal information, especially when the modality of recall is considered less important than the accuracy of performance.

Significant limitations are noted when using the CVLT-II SF with a sample of stroke rehabilitation patients. First, when examining this test's validity based on correlations with other neuropsychological measures, it may be interpreted that the domains assessed by the CVLT-II SF are not limited to attention and memory for verbal information. Instead, it may also have a role in verbal abstraction or organization of verbal information. Further external validation is required.

The abbreviated nature of this test, developed with the intention to assess patients with moderate to severe cognitive function, has restricted use. Reducing the CVLT's list length may make some of its indices less valuable in achieving their original functions. For example, the test does not appear useful for interpreting a stroke patient's use of semantic clustering or recognition cues. Thus, this test is unlikely to differentiate individuals with encoding deficits from those with retrieval deficits. This is a tremendous weak point of the measure, as many clinicians use list-learning tests with a goal of identifying patterns of learning and memory. As a result, current use of this test to distinguish patterns of memory profiles may produce misleading interpretations and uninformed clinical decisions about diagnosis and treatment.

The CVLT-II SF can make a valuable contribution to the clinical assessment of learning and memory for verbal information as long as its limitations are recognized. As with any other neuropsychological instrument, the information gathered using the CVLT-II SF should not be interpreted in isolation, but rather it should be collaborated with information obtained using a comprehensive neuropsychological battery as well as available supplementary information. This is especially necessary if faced with an individual whose performance is less than optimal on the task, as further exploration will be required to determine the underlying reasons for the poor performance. In such cases, further assessment would probably require administration of additional measures of attention and memory.

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